

# **RECENT ADVANCEMENTS IN COMPUTATIONAL INTELLIGENCE AND DESIGN ENGINEERING**

Edited by Dac-Nhuong Le, Abhishek Dhar, Ranjan Kumar, Saravanan Muthaiyah and Saurabh Adhikari



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### About the Book

The book of conference proceedings is a storehouse of information that has been updated with new research findings. The main goal of this volume is to put all the technologies that have to do with computing and communication on a single platform. International Conference on Computational Intelligence and Design Engineering (ICCIDE 2023) is a multidisciplinary conference focused on bringing together recent advancements in the field of engineering, computer science and Mathematics. The key features of the conference include a common platform for research and innovation work related to next generation computation, computation, Mathematics in computation as well as engineering research to achieve industry 5.0 mission. The scope of the "International Conference on Computational Intelligence and Design Engineering (ICCIDE 2023)" is to bring together researchers, scientists, engineers, and professionals from diverse scientific disciplines to promote the integration of knowledge and methodologies across different fields. The conference aims to foster interdisciplinary collaboration and explore innovative approaches to address complex scientific and engineering challenges. The role of IT in every nook and cranny is a remarkable accomplishment. right from agriculture sector to exploration of planetary-science. This conference takes on a journey to all the stakeholders as a treat to establish a captivating knowledge for the forthcoming student community. The increase in computing power and sensor data has driven Information Technology on end devices, such as smart phones or automobiles bringing together the practitioners of IT much delightful. The conference covers different aspects of science and technology like applications of AI and ML for sustainable manufacturing and production systems, computational modelling, mathematics and computing, Engineering for Industry 5.0 and many more. The uniqueness of the conference lies in its endeavor to bring industry-academia on common platform to foster mutual growth and benefits by promoting multidisciplinary research works being presented on a common platform.

### Preface and Acknowledgement

The main goal of this proceedings book is to bring together top academic scientists, researchers, and research scholars so they can share their experiences and research results on all aspects of intelligent ecosystems, data sciences, and mathematics. The purpose and aim of the International Conference on Computational Intelligence and Design Engineering (ICCIDE 2023) is to bring together researchers, scientists, engineers, and professionals from diverse scientific disciplines to promote the integration of knowledge and methodologies across different fields. The conference aims to foster interdisciplinary collaboration and explore innovative approaches to address complex scientific and engineering challenges. The aim of the conference is to provide a platform to the researchers and practitioners from both scholastic as well as industry to meet and share state-of-the-art development in the field. The Conference goals for a comprehensive and multidisciplinary review of information and communication technologies that could be achieved through various functionalities of service at the Conference.

We are very grateful to Almighty for always being there for us, through good times and bad, and for giving us ways to help ourselves. From the Call for Papers to the finalization of the chapters, everyone on the team worked together well, which is a good sign of a strong team. The editors and organizers of the conference are very grateful to all the members of Taylor and Francis Team, especially Vindhya Pillai, Shatakshi Mishra, and Shailesh Shahi, for their helpful suggestions and for giving them the chance to finish the conference proceedings. We're grateful that reviewers from all over the world and from different parts of the world gave their support and stuck to their goal of getting good chapters submitted during the Pandemic.

Last but not least, we want to wish all of the participants luck with their presentations and social networking. This conference can't go well without your strong support. We hope that the people who went to the conference enjoyed both the technical program and the speakers and delegates who were there virtually. We hope you have a productive and fun time at ICCIDE 2023.

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# 1. A comprehensive review on the utilization of rice husk ash as a partial substitute for cement in concrete

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#### Abstract

The current study thoroughly examined available literature concerning rice husk ash (RHA), focusing mainly on how RHA's particle characteristics influence the mechanical, durability, and fresh concrete properties when partially utilized as a replacement for cement. The pozzolanic properties of RHA, including its specific surface area, particle fineness, and amorphous silica content, are crucial factors that can be enhanced through controlled burning and grinding before incorporation into concrete. Typically, RHA particles exhibit a non-uniform shape characterized by distinct features, uneven dispersion, and porous surface structures. Incorporating RHA into cement results in concrete with favourable fresh properties such as workability, consistency, and setting time, attributed to RHA's finer particle size than cement and the involvement of amorphous silica processes. Due to its high pozzolanic characteristics, RHA can effectively substitute cement by upto 20% without compromising the performance of concrete.

Keywords: Green concrete, Rice husk ash, RHA characterizations, Fresh concrete, Mechanical properties, Durability attributes, Partial cement replacement.

#### 1. Introduction

Researchers are actively seeking alternatives to concrete that maintain strength while reducing construction costs. Cement, a primary ingredient in concrete, contributes significantly to environmental pollution through CO2 emissions during production. Substituting some cement with auxiliary materials can lower concrete production costs. With millions of tons of rice husk generated annually from industrial and agricultural processes, approximately 20–25% RHA by weight can be obtained through complete incineration. Given RHA's non-crystalline silica content, it shows promise as a partial replacement for Portland cement. Ravande et al. observed that rice husk ash cement comprising up to 50% ash exhibited greater compressive strengths than typical Portland cement blocks.

While widespread research has examined using RHA to enhance concrete's mechanical strength, durability, and other characteristics, limited studies have focused on naturally burnt RHA in concrete. This study intends to compare the mechanical behaviour of concrete containing RHA with control concrete at various stages, investigating the strength of concrete with 10% and 15% RHA replacements. Specifically, the study aims to assess the strength of concrete ground for less than ten minutes and containing 10% and 15% RHA replacements. Additionally, the study contrasts earlier findings on the strength, pozzolanic behaviour, and physical/mechanical characteristics of RHA with the outcomes of the current investigation.

#### 2. Materials and Methods

#### 2.1 RHA Production

As rice is the sole food crop cultivable in tropical regions during monsoon season, Asia holds the global lead in rice production. Disposing of rice husks poses a significant challenge, leading to the construction of larger mills. Throughout the growth period, the protective coating of rice seeds, known as rice husks, shields them from physical damage and assaults by pests, insects, and pathogens. These husks are separated from the grains during the milling. Brown rice results from milling the grain to remove the husk, while white rice is produced by further milling to eliminate the brown layer.

Due to its diverse properties, rice husk ash (RHA) has extensive applications. This exceptional insulator is utilized in steel foundries, residential insulation manufacturing, and the production of refractory bricks, among other industrial processes. It is an active pozzolana with plentiful uses in the concrete and cement sectors. Moreover, owing to its remarkable absorbency, it serves in water filtration to remove arsenic and absorb oil from challenging surfaces.

Two methods, regulated incineration and open field burning of rice husks, can produce RHA. The temperature and duration of combustion influence the carbon and amorphous silica content in RHA. Well-burned and finely ground RHA produce more robust, durable concrete and cement. This pozzolanic material with consistent characteristics can be attained only under well-controlled burning conditions. Consequently, the duration of the process and temperature determine the type of silica formed post-combustion of rice husk. Literature suggests that burning rice husks between 400 and 1100 degrees Celsius yields RHA with high pozzolanic activity, retaining crystalline or amorphous silica properties.



Figure 1: Rice Husk Ash used for concrete

#### 2.2 Physical Characteristics of RHA

The physical attributes of rice husk ash (RHA) are influenced by various processing factors such as grinding, temperature, separation methods, duration of burning, and burning techniques. Controlled combustion and finely grinding RHA for structural concrete applications can enhance its pozzolanic properties, hinge on its particle fineness, specific surface area, and amorphous silica content.

The pore structures of RHA, which differ based on calcination temperature, rice husk source, burning duration, holding period, etc., comprise large interconnected pores and small pits, as documented by numerous researchers. Moreover, acid-leaching burnt husks can produce RHA with a high-purity silica concentration. Researchers like Krishna, N. K., and colleagues note that RHA exhibits a significantly lower specific gravity than cement, alongside a lower bulk density. The filling of concrete pores by RHA, resulting in impermeability, is facilitated by its low bulk density, thereby increasing the volume occupied per unit mass. Furthermore, E. Mohseni et al. report that RHA possesses a larger surface area (4091 cm<sup>2</sup>/g compared to 3105 cm<sup>2</sup>/g for Portland cement).

Data from various studies summarized in Table 1 reveal RHA's specific gravity and mean particle size. The fineness of RHAmixed cement rises with higher RHA content additions (from 330 m<sup>2</sup>/kg at 0% RHA to 550 m<sup>2</sup>/kg at 25% RHA), as documented by A. A. Raheem and M. A. Kareem. This rise in fineness with RHA concentration is attributed to RHA's lower density than cement. The physical properties of RHA-mixed cements at different replacement amounts are shown in Table 2. As anticipated, when RHA content rises, mixed cement's fineness rises and the residue on a 45 µm screen falls. A larger proportion of coarser OPC clinker is the reason for the higher residue in low RHA-mixed cement. The increased fineness of mixed cement compared to control cement can be ascribed to their lower specific gravity. The soundness range for RHA mixed with cement typically falls between 4 and 6 mm at varying replacement percentages.

Parameters		Residue on 45 µm sieve (%)	Fineness (m <sup>2</sup> / kg)	Soundness (mm)	Specific gravity (g/cm <sup>3</sup> )
Percentage of	0	17.87	330	4	3.19
RHA Replacement	5	14.7	410	6	3.09
	7	14.63	409	5	2.97
	11.25	12.13	494	6	2.94
	15	17.63	497	5	2.89
	20.25	15.7	509	5	2.8
	25	10.87	550	6	2.69

 Table 1: Physical characteristics of RHA mixed cement

Furthermore, as documented in various studies, the colour of RHA arrays from white to grey to black, with variations depending on the carbon content utilized in the process. Quick combustion times resulting in inadequate RHA combustion lead to greater carbon content.

#### 2.3 Chemical Characteristics of RHA

The chemical characteristics of RHA undergoes slight variations based on temperature and burning duration, albeit not markedly. Controlled burning of silica to maintain it in a non-crystalline state can yield highly pozzolanic ash. Most studies affirm that the formation of amorphous reactive ash is notably influenced by burning temperature. As reported in the literature, the oxide content of RHA samples is depicted in Table 3. The silica component primarily dictates the pozzolanic reactivity and chemical composition of RHA. Table 3 consistently demonstrates that the silica percentage of RHA surpasses 70% in most investigations. Nevertheless, controlled combustion and grinding techniques can showcase pozzolanic reactivity.

 Table 2: Oxide content of the RHA sample as determined by X-ray fluorescence (XRF) examination

Si <sub>o</sub> 2	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	SO <sub>3</sub>	Na <sub>2</sub> O	K <sub>2</sub> O	Others	LoI	$SiO_2 + Al_2O_3 + Fe_2O_3$
87.22	0.70	1.68	2.12	1.18	0.04	0.20	1.12	1.52	1.06	89.6
91.15	0.41	0.21	0.41	0.45	0.45	0.05	6.25	-	0.45	91.77
87.89	0.19	0.28	0.73	0.47	-	-	3.43	-	4.36	88.36
83.74	0.29	0.67	0.74	0.86	0.87	0.091	2.84	0.51	8.39	84.7
84	1.35	1.45	3.17	-	0.92	-	-	-	-	86.8
90.16	0.11	0.41	1.01	0.27	-	0.12	0.65	-	-	90.68
74.35	1.379	1.029	1.39	1.06	-	-	3.51	-	1.50	76.758
93.6	0.2	0.3	0.8	0.4	0.1	0.7	1.1	-	2.5	94.1
90.6	1.7	0.7	0.1	0.8	-	-	2.4	2.65	<6	93
85.3	-	0.817	1.42	0.81	0.23	-	2.37	4.881	-	86.117
86.73	0.04	0.61	0.39	0.08	1.32	9.76	0.01	-	0.54	87.38
81.8	0.38	0.78	1.8	0.9	0.56	0.05	3.1	5.56	-	82.96
93.5	0.55	0.23	1.11	0.31	0.07	0.1	1.4	-	-	94.28
87.8	0.4	0.3	0.7	0.6	0.1	0.5	2.2	-	2.2	88.5
88.07	1.35	0.22	1.04	0.74	0.49	1.15	2.02	2.31	2.61	89.64
86.98	0.84	0.73	1.4	0.57	0.24	0.11	2.46	-	5.14	88.55
96.84	1.03	0.38	0.47	0.32	-	0.03	0.81	0.1	-	98.25
87.8	0.4	0.3	0.7	0.6	0.1	0.5	2.2	-	2.2	88.5
94.91	0.37	0.79	0.98	0.26	0.09	0.02	1.67	0.85	0.06	96.07
91.56	0.19	0.17	1.07	0.65	0.47	-	-	4.89	-	91.92
92.19	0.09	0.10	0.09	0.41	0.41	1.64	0.05	0.72	4.14	92.38

## 2.4 Material Assortment and Preparation of Specimen

Three distinct water-to-cement ratios (0.40, 0.50, and 0.60) were used to create the specimens, which also included crushed stone, coarse sand, and standard Portland cement. The coarse aggregate consisted of appropriately graded crushed stone with a maximum size of 20 mm and a specific gravity of 2.64, while the sand had a specific gravity of 2.6 and a fineness modulus of 2.70. For specimen preparation, naturally, entirely burned rice husk ash (RHA), depicted in Figure 1, underwent grinding in a machine grinder without additional processing. The bulk density of RHA was 106 kg/m<sup>3</sup>, with a specific gravity of 2.01. The cement employed met IS: 1489–1991 standards.

RHA was used to partially replace cement specimens at 10% and 15% of the total cement content by weight to investigate the strength variation of concrete. Table 3 provides a comprehensive list of each component and its quantity per  $m^3$  of concrete.

#### 2.5 RHA Usage in Concrete

In the absence of appropriate admixtures, the workability of concrete diminishes with increasing cement replacement by RHA. Researchers recommend the utilization of admixtures and a low water-to-cement ratio when employing RHA in concrete. Studies indicate that RHA, owing to its high silica content, enhances the durability of concrete. The proportion of RHA substitution varies relative to the weight of cement, typically ranging from 5% to 30%. Integrating by-products like rice husk ash into concrete reduces construction expenses, enhances concrete quality, and mitigates pollution.

A primary experimental study optimized the cement content in concrete mixes with diverse water-to-cement ratios and hot mix asphalt residual concentrations. RHA, obtained from naturally burned sources, underwent a ten-minute mechanical grinding process before utilization. The mechanical characteristics of concrete with RHA added in place of some of the cement were noted and contrasted with control concrete.

#### 2.6 Slump Test

Slump tests were performed on RHA-used and ordinary cement concrete to assess workability per IS: 1199–1959.

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#### 2.7 Water Sorption Test

As reported, water absorption assessments were conducted on cylindrical concrete specimens featuring 0%, 10%, and 15% RHA replacement. The specimens were weighed after drying for 24 hours at  $100 \pm 5$  °C in an oven. Subsequently, the samples were immersed in room-temperature water for a complete day. After 24 hours, the specimens were removed from the water, and their surfaces were wiped with a towel to achieve saturation.

Utilizing the following formula, determine the water absorption capacity under surface dry conditions and weight taken (Wssd):

Water absorption (%) = ((Wssd-Wd)/Wd) \*100

#### 3. Results and Discussions

#### 3.1 Slump Value

Due to its fine grinding, adding RHA to concrete enhances the overall cohesion and stiffness of the mixture. The findings from the slump test indicate that concrete mixtures containing rice husk ash exhibited reduced slump. Waterreducing admixtures are recommended for RHA concrete mixtures to maintain workability. The decrease in slump coincided with the increase in RHA content.

#### 3.2 Water Adsorption Capacity

With all other components held constant, the water-to-cement ratio impacts the water absorption capacity of concrete. Compared to control concrete, concrete incorporating RHA tends to absorb more water. This variation, ranging from 10% to 28%. The increased porosity of RHA-utilized concrete compared to control concrete accounts for this phenomenon. Concrete porosity escalates as the ratio of cement to water increases.

#### 3.3 Compressive Strength Variation

Table 3 presents the findings of the compressive strength test conducted on concrete cylinders. The results indicate a decrease in compressive strength with increased RHA replacing cement. It has been observed that concrete strength diminishes as water content rises. The maximum compressive strength of plain cement concrete (0% RHA) surpasses any minor cement replacement with RHA. Replacement of 10% of cement with RHA results in higher compressive strength. However, Table 4 reveals that substituting 15% of cement with RHA led to an average drop in compressive strength ranging from 10% to 12%.

The primary reason behind the decline in concrete strength, when RHA substitutes a portion of cement in the mix, is attributed to the coarse characteristics of RHA. Adding RHA instead of cement reduces the density and porosity of the mixture, consequently weakening the concrete. Moreover, RHA-replaced concrete with higher water-to-cement ratios exhibits significant porosity, further decreasing strength.

At 28 days of age, the compressive strength of the specimen with 10% RHA replacement differs by 1–2.5% from that of regular cement concrete. Thus, considering strength and workability, replacing cement with RHA proves sustainable. The results confirm that the trend of strength gain in RHA-replaced concrete closely aligns with that of plain cement concrete during the curing period.

Specimen W4A0 attains a maximum bulk density of 2.51 g/cm<sup>3</sup>, whereas sample W6A15 exhibits a minimum bulk density of 2.34 g/cm<sup>3</sup>. Consequently, the concrete's bulk density and concurrent strength decline as the water-cement ratio and RHA concentration increase. Reducing RHA particle size is necessary to enhance specific surface area and boost bulk density in RHAreplaced concrete. Previous research suggests that lengthening the grinding period to reduce RHA particle size decreases concrete porosity, thereby increasing bulk density. Consequently, an increase in specific surface area and bulk density contributes to an elevation in concrete strength.

Specimen ID	Compro after cu	essive st ring, N/	% Variation in compressive strength	
	7 days	14 days	0% RHA concrete after curing	
$W_4A_0$	23.8	28.6	35.6	0
W5A0	21.3	26.3	31.7	0
W6A0	19.38	23	29.4	0
W4A10	23.2	27.4	35	1.6

 Table 3: Specimen Compressive strength

Table 3:	(Continued)
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W5A10	20.9	25.7	30.9	2.5
W6A10	18.9	22.4	28.8	2.04
W4A15	21	26	31	12.9
W5A15	17.5	23	28.6	9.78
W6A15	16.3	20.2	26	11.56

#### 3.4 Variation in Flexural Strength

Table 4 presents the outcomes of the flexural strength test, increased by 20-30% after 7 days of curing and by 50% after 14 days. Notably, concrete with 0% RHA exhibits the most substantial strength growth at 28 days of curing age, while concrete with 10% RHA displays the lowest strength. On average, 10% of cement was replaced. Specimens with lower waterto-cement ratios show less variance in flexural strength. The average reduction in flexural strength was 25%, with a 15% substitution of cement. Therefore, when taking into account flexural strength, it is recommended to employ a lower water-to-cement ratio (10% replacement of cement by RHA). These results demonstrate that there is very little variation in the strength of the RHA-replaced concrete in the first 14 days.

 Table 4: Flexural strength of specimens

Specimen	Com	pressive	2	% variation in		
ID	strength after			flezural strength		
	curing	g, N/m	m <sup>2</sup>			
	7	14	28	7	14	28
	days	days	days	days	days	days
W <sub>4</sub> A <sub>0</sub>	1.26	2.50	5.21	0	0	0
W5A0	1.15	2.22	5.13	0	0	0
W6A0	1.08	2.03	4.95	0	0	0
W4A10	1.25	2.40	4.85	0.79	4.00	6.91
W5A10	1.13	2.18	4.69	1.7	1.80	8.58
W6A10	1.06	1.97	4.13	1.85	2.96	16.56
W4A15	1.21	2.33	3.96	3.97	6.8	23.99
W5A15	1.12	2.16	3.87	2.61	2.7	24.56
W6A15	1.05	1.95	3.58	2.78	3.94	27.68

#### 3.5 Variation in Tensile Strength

The results of the tensile test of concrete specimens with and without RHA partially replacing the cement are listed in Table 5. For both ordinary and RHA-used concrete, the tensile strength of concrete decreases as the water-tocement ratio increases. Tensile strength was appropriately lost when 10% of the cement in the concrete was replaced with RHA, according to both the current study and previous studies.

Table 5: Tensile strength of specimens

Specimen ID	Tensile strength after 28 days curing, N/mm <sup>2</sup>	% Variation in tensile strength from 0% RHA
W <sub>4</sub> A <sub>0</sub>	4.80	0
W5A0	4.65	0
W6A0	4.41	0
W4A10	4.46	7.08
W5A10	4.23	9.03
W6A10	3.98	9.75
W4A15	4.16	13.33
W5A15	3.91	15.91
W6A15	3.51	20.41

#### 4. Conclusions

Based on the findings of the current study and other research concerning tensile strength, compressive strength, and flexural strength of concrete, the utilization of RHA as a partial replacement for cement up to a certain threshold proves satisfactory and beneficial in achieving the desired strength with cost-effectiveness. The overarching conclusions of the study are as follows:

- 1. Rice husk ash, obtainable through controlled or spontaneous burning and utilized with or without additional processing, is a suitable supplementary cementitious material.
- 2. Incorporating RHA instead of a portion of cement in concrete construction facilitates the reduction of environmental pollutants and cost savings.
- 3. Concrete containing RHA, falling within the density range for normal-weight concrete, is suitable for general-purpose applications.
- 4. As the substitution of cement with RHA increases, the slump decreases, and water demand rises.

5. Comparable compressive, flexural, and tensile strengths are shown by concrete specimens that have 10% more RHA added to the cement than control specimens. The integration of RHA in concrete mitigates the reduction in strength caused by specific chemical attacks.

#### 5. Acknowledgement

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# 2. A review on performance improvement of differential pressure flowmeter

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#### Abstract

Venturimeter device works on the principle of Bernoulli's theorem. This device increases the velocity of any fluid at any point in a pipe. When a fluid flows through a pipe with a small cross-sectional area, the pressure drops suddenly, increasing the flow's velocity. Actual and theoretical discharge calculation is possible with the use of a venturimeter device. These two values give the value of co-efficient of discharge. The orificemeter device is defined as a plate having a central hole which is placed across the flow of a liquid and is usually between flanges in a pipeline. With the help of orificemeter, it is possible to calculate the co-efficient of discharge from actual and theoretical discharge. The value of Cd becomes more in case of venturimeter and is always equal to or less than 1.

Keywords: Venturimeter, Bernauli's theorem, orificemeter, Discharge.

#### 1. Introduction

Actually, the flowmeter device is a flow rate measuring instrument, used for determination of linear or non-linear mass and volumetric liquid flow (Manish R. Bhatkar et al. 2001). It may be of various types, like differential pressure flowmeter, volumetric flowmeter etc. (Preeti V. Ban et al. 2008).

Differential pressure flowmeter states that the flow of a liquid increases with decrease of pressure and it uses the equation developed by Bernoulli's.

Orificemeter, venturimeter are the varieties of differential flowmeter.

A cylindrical tube containing a plate having a small hole at its middle is known as orificemeter. The middle thin hole forces the fluid to flow faster through the hole for maintaining the rate of flow (David Boyajian et al. 2011). The position of vena contracta (point of maximum convergence) occurs at slight downstream point from actual location. Due to this reason, orificemeter is less accurate than venturimeter. Beyond the position of vena contracta, the fluid again expands and velocity decreases with increase of pressure. The term  $\beta$ -ratio is actually the ratio of diameter of the orifice to that of the pipeline provided (T. Zirakian et al. 2015).

It consists of a conical converging inlet, a discharging cone and one cylindrical shape throat (Lienhard JH et al. 2021). Venturimeter has no projections into the fluid and no sharp corners. Due to the effect of converging inlet, the area of fluid decreases and ultimately velocity increases and pressure decreases (Sanghazi Chirag et al. 2016). At the center of cylindrical throat, the fluid pressure attains a least value, where neither velocity nor pressure will change (Zhao Ben et al. 2020). At the time of entering in diverging section, the pressure will be recovered largely and ultimately fluid velocity reduces. The disadvantage of this type of flowmeter is its high initial cost and second is more space requirement for installation and operation.

#### 2. Literature Review

Researcher Amin Pormehv (2020) of California State University carried out several number of experiment on orificemeter device and its real life applications at the time of analyzing the effect of variables like flow, pressure, velocity and volume.

J. Fank (2013) was also carried out the research on same topics at Department of Civil Engineering at Northridge, USA. The article was published on 27th June, 2020. Orificemeter is also used for gas flow measurement. This types of flowmeter is used for such fluids which are steady or varies slowly with time.

Researcher, Emerson (2015) of STBS College of Engineering, namely 'Comparative Analysis of Different Orifice and Geometries for Pressure Drop' told that the difference of pressure from the c/s area of flow passage reduction may be calculated for the flow rate. It is also explained here, that for lowering of the energy cost for flow meter, minimization of this loss is necessary.

Research paper by Akshay R. Kadama (2012) on the topics of "Acoustic Study & Behavior of Flow" explained that, orifice flowmeter is actually designed to decrease the pressure or to increase the velocity of fluid flow.

Researcher Michel Reader Harries (2011) invented that when fluid flows through a clean and contaminated plates has a variety of venacontracts location and discharge co-efficient value. He has carried out her works on orifice flowmeter. Oil, grease, pipeline sludge etc. contaminates the orifice plates, discharge co-efficient also increased.

Researcher V. G. Fister (2010), explained the effect of beta ratio for prediction of pressure loss co- efficient in the laminar and turbulent flow in Newtonian and Non- Newtonian fluid

Researcher Patel Mitches (2018) carried out a several number of work on venturi type flowmeter. He was also conducted the work on calibration of venturimeter and loss of water head at the cross- sectional part of a pipe. To minimize the pressure drop in future work, different parameters was also defined to be varied in each combination.

Scientist Ahamed Jahith (2019) constructed a computational type model of venturitype flowmeter in the year of 2019. It was used for calibration purpose as an efficient device in leak of costly experimental work. For analysation of experimental data by Bernoulli's equation and for calculation of theoretical data in case of venturimeter study, the above research work helps a lot.

Researcher H. Ameresh (2017) invented that, the dynamic type flow analysis can be carried out by different inlet diameter of venturimeter, like 25 mm, 30 mm and 35 mm. In this particular work, inlet dia of above type were used for construction of venturimeter models.

#### 3. Methodology

All clamps are checked, whether they are in tight condition or not. Then, main tank water level is observed for suction of pump. For venturimeter operation, outlet valve is open and all valves of the orificemeter are closed the of the orificemeter line. Close the by-pass valve of the pump for a remarkable discharge variation as per requirement. Finally, the pump is switched on, then gate valve is opened and water is allowed to flow. Now air bubbles are removed, if any. Care should be taken for avoiding running of mercury. Then, for obtaining a steady flow, a normal waiting time is required. Then, initial water level of the discharge measuring tank is recorded after closing the gate valve of the tank. Time required for 10 cm rise in water is recorded and flow rate is also calculated. Finally, manometer difference is noted. All measurement should be taken after attaining a steady flow. Same procedure is repeated for varying discharge and minimum three readings are required.

For increased accuracy of orifice / venturi type flowmeter, the water coming to the main tank should be clean from all types of impurities. For this reason, a good quality filter should be connected at the starting point of pipe line, provided to the main tank. Otherwise, filtered water should be used in the main tank and it should be changed at regularly.

#### 3.1 Improvement in the Field of Flowmeter

Several countries are doing research enormously on flowmeter nowadays, like, U.S.A., Saudi Arabia, South Africa, Israel, Egypt, Middle East, Africa, etc.

At present decades, there has been a considerable development in the field of flowmeters. At least 100 flowmeters are available commercially now-a-days. Modern types of flowmeters are continually introduced.
The sensitivity of flowmeters has been increased continuously. Various research efforts have been made in order to improve the performance of flowmeters. A fundamental understanding of the effects of flowmeters operational conditions upon the discharge co-efficient is necessary to reduce or to installation effects, which decrease the accuracy of flowmeters (R. Fank – 2013).

In present decades, various research works are continuing in USA, Canada, France and in India by various researchers to get more and more accurate result for co-efficient of discharge verification by using different models of flowmeters.

Present research work on internal section of venturimeter (Figure 1) shows that, there may be a variation in the discharge co-efficient due to slight irregularities in internal section of flow pipe (S.K. Patel – 2015). For this reason, at present before installing venturi flowmeters in a pipe line, their internal irregularities are checked up to 0.1% accuracy.



Figure 1: Differential pressure flowmeter

#### 3.2 Head Difference Management

When water contains impurities or water becomes more turbid, it causes decreased c/s area of flowmeter pipes, which ultimately causes reduced discharge and effective pressure of fluid. As a result, head difference becomes low for orifice/venturi type differential pressure flowmeter. Head difference goes on reducing with time. Research work shows that, in case of normal water (having turbidity value, of about 25ppm) head difference may drop up to 6 c.m. from the standard value of 9 c.m., after a use of 90 / 95 times. It continues a straight path of about 130 no. of use.

But, in case of filtered water (having turbidity value of 2 ppm), head difference remains same up to prolonged time (of about 60 / 62 times use) and then drop very slowly and remains more or less same up to about 130 times use.

The following two Tables 1 and 2 can give an idea about the matter:

Table	1:	Data	for	normal	water	sample	e, w	here
tested	tuı	cbidity	is is	25 ppm	L			

SERIAL NO	NO. OF USE	HEAD DIFFERENCE IN CM.
1	0	9.0
2	18	9.0
3	30	8.0
4	45	7.5
5	62	7.0
6	75	6.5
7	92	6.0
8	110	6.0
9	120	6.0
10.	130	6.0

Table 2: Data for normal water sample, where tested turbidity is 2 ppm

SERIAL NO	NO. OF USE	HEAD DIFFERENCE IN CM.
1	0	9.0
2	18	9.0
3	30	9.0
4	45	9.0
5	62	9.0
6	75	8.9
7	92	8.9
8	110	8.8
9	120	8.8
10	130	8.8

#### 3.3 Research Gaps in the Field

In Clemens Herschell types of venturimeter, the major problems are the determination of exact height of the mercury. It creates variations of the head difference of flowmeters, which ultimately affect the value of Cd.

The main drawback in the Clemens type of flowmeters is the preservation of the mercury. Actually, during taking head difference, in any flowmeter, when vales are operated by manual power, there is a chance of running away of mercury in water.

During operation, when outlet valves are cleaned, as it is manually operated, so there is a chance of going out mercury, due to mercury due to improper pressure created by operator.

During testing of a new machine, mercury becomes brighter and it gives better visibility, which helps in taking exact readings. But in case of Clemens types flowmeters, after one/two years, colour of mercury becomes blackish due to coming of impurities in water and then head difference is not perfect, which ultimately gives imperfect value of Cd.

Due to large size of flowmeters, it takes more spaces to install and it is also a major problem.

#### 9.0 9.0 8.9 8.8 8.8 Ω 9 ÷ 8 IN 7 HEAD DIFFERENCE 6 5 4 2 1

18 30 45

NO OF USES

92 110 120 130

HEAD DIFFERENCE DROP GRAPH FOR FILTERED WATER

62 75

Since value of Cd is directly dependent on pump condition and its capability, so it is not possible to verify it during pump breakdown.

#### S 9 8 HEAD DIFFERENCE IN 7 6 T 0 5 4 2 1 18 30 45 62 75 92 110 120 130 ND DF USES HEAD DIFFERENCE DROP GRAPH FOR NORMAL WATER

#### 3.4 Effect of Head Difference in Cd Value

Co-efficient of discharge (Cd) is mostly dependent on head difference available on flowmeter. When head difference drops, Cd value becomes less. Until, head difference becomes stagnant at certain value, Cd value gradually reduces and then attains at a certain limit.

The following Table 3 may give a clear picture:

Table 3:	Variation of	Coefficient of Discharge (C	Cd)
values wi	ith respect to	head difference	

SL NO	Head Difference IN CM	Cd VALUE	ERROR IN Cd VALUE
1	9.0	0.9	NIL
2	8.5	0.86	0.04
3	8.0	0.82	0.08
4	7.5	0.78	0.12
5	7.0	0.74	0.16
6	6.5	0.71	0.19
7	6.0	0.68	0.22

## 4. Conclusions

When filtration unit is connected in series to that of orifice / venturi type flowmeter, the mercury in manometer is not blackened. As a result, manometer difference is clean which gives accurate Cd value. Outlet valve should not be closed completely in any case, otherwise created excessive pressure may cause dismantling of PVC pipe resulting an electrical hazard. Extreme care should be taken during operation of manometer valve so that during air bubbles removal, mercury may not come out. At the time of taking 10 cm water height in discharge measuring tank, extreme care should be taken so that water may not be discharged through the opening provided at the top of the discharge tank. When flowmeter remains unused or after completion of the experiment, the water in main tank and in discharge tank should be discharged fully, otherwise mosquito hazard may be created. Machines should be operated frequently or pump should be switched on at a regular interval, otherwise the centrifugal pump installed in machine will not work properly and may lead to frequent repair.

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# 3. Advancements in data generation with artificial intelligence

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#### Abstract:

The exponential growth of data-driven technologies has underscored the critical importance of high-quality datasets for training and evaluating machine learning models. However, acquiring labelled datasets can be challenging and expensive, often constrained by factors such as privacy concerns, data scarcity, and class imbalances. To address these challenges, researchers have turned to artificial intelligence (AI) techniques for data generation. This paper provides a comprehensive overview of data generation methods leveraging AI, including Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), Recurrent Neural Networks (RNNs), Transformer Models, and domain-specific techniques. We discuss the principles behind each method, their applications in various domains, and challenges associated with synthetic data generation. Furthermore, we explore emerging trends and future directions in the field, such as privacy-preserving data generation and ethical considerations.

Keywords: Data generation, Artificial Intelligence, Generative Adversarial Networks, Variational Autoencoders, Recurrent Neural Networks, Transformer Models, Synthetic Data, Privacy Preservation, Ethical Considerations.

## 1. Introduction

The rapid proliferation of data-centric technologies has underscored the pivotal role of high-quality datasets in facilitating the development and evaluation of machine learning models. These datasets serve as the bedrock upon which algorithms learn patterns and make predictions. However, procuring labelled datasets that adequately represent real-world scenarios can be arduous and resource-intensive. Challenges such as privacy concerns, data scarcity, and class imbalances often impede the acquisition of diverse and comprehensive datasets. Consequently, researchers have increasingly turned to artificial intelligence (AI) techniques for data generation to alleviate these constraints and augment existing datasets.

#### 1.1 Importance of High-Quality Datasets

High-quality datasets are indispensable for training robust and accurate machine learning models. These datasets not only enable algorithms to learn intricate patterns but also facilitate the evaluation of model performance. Moreover, they serve as the foundation for advancements in AI research and applications across various domains, including healthcare, finance, transportation, and cybersecurity.

#### 1.2 Challenges in Data Acquisition

Despite the paramount importance of highquality datasets, several challenges hinder their acquisition. Privacy concerns surrounding sensitive data restrict access to certain datasets, thereby limiting their utility for research and development purposes. Furthermore, data scarcity, especially in niche domains, exacerbates the challenge of obtaining comprehensive datasets. Additionally, class imbalances within datasets can skew model performance and hinder the generalisation of machine learning algorithms.

## 1.3 Role of AI in Data Generation

To address the challenges associated with data acquisition, researchers have leveraged AI techniques for data generation. By employing sophisticated algorithms, such as Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and Recurrent Neural Networks (RNNs), researchers can synthesize realistic data samples that mimic the characteristics of real-world datasets. These AI-driven data generation techniques offer a scalable and cost-effective means of augmenting existing datasets, mitigating privacy concerns, and addressing class imbalances.

### 1.4 Objectives of the Paper

In this paper, we provide a comprehensive overview of data generation methods leveraging artificial intelligence. We examine the underlying principles of prominent AI techniques for data generation, including GANs, VAEs, RNNs, Transformer Models, and domain-specific approaches. Furthermore, we explore the applications of these techniques across various domains, discuss challenges associated with synthetic data generation, and highlight emerging trends and future directions in the field, such as privacy-preserving data generation and ethical considerations.

## 2. Background

Data generation techniques encompass a diverse array of approaches aimed at synthesizing data samples that closely resemble real-world observations. Traditionally, data generation relied on manual annotation or sampling from existing datasets. However, advancements in AI have ushered in a new era of data generation, wherein algorithms autonomously generate synthetic data based on learned patterns and distributions.

## 2.1 Traditional Approaches vs. AI-Based Approaches

Traditional approaches to data generation often involve manual annotation or sampling from existing datasets, which can be labour-intensive and time-consuming. In contrast, AI-based approaches leverage sophisticated algorithms to autonomously generate synthetic data that exhibit realistic characteristics. These AI-driven techniques offer scalability, flexibility, and efficiency in data generation, thereby overcoming many of the limitations associated with traditional approaches.

## 2.2 Evolution of AI in Data Generation

The evolution of AI in data generation has been marked by significant advancements in algorithmic sophistication and computational efficiency. Early approaches, such as rule-based systems and statistical models, laid the foundation for subsequent developments in AI-driven data generation. The advent of deep learning techniques, particularly GANs, VAEs, and Transformer Models, revolutionized the field by enabling the generation of high-fidelity synthetic data across various modalities, including images, text, and audio.

## 3. Generative Adversarial Networks (GANs)

Generative Adversarial Networks (GANs) represent a class of neural network architectures designed for generative modelling. Introduced by Ian Goodfellow and his colleagues in 2014, GANs consist of two neural networks: a generator and a discriminator. The generator network synthesizes realistic data samples, while the discriminator network distinguishes between real and synthetic samples. Through adversarial training, wherein the generator seeks to deceive the discriminator and vice versa, GANs learn to generate data samples that closely approximate the underlying data distribution.

## 3.1 Architecture of GANs

The architecture of a GAN comprises two interconnected neural networks: the generator and the discriminator. The generator network takes random noise vectors as input and generates synthetic data samples, such as images or text. The discriminator network, on the other hand, receives both real and synthetic data samples as input and predicts whether each sample is real or synthetic. During training, the generator aims to generate data samples that are indistinguishable from real samples, while the discriminator learns to differentiate between real and synthetic samples.

## 3.2 Training Process

The training process of a GAN involves iterative optimization of the generator and discriminator networks through adversarial training. Initially, the generator generates synthetic data samples from random noise vectors, while the discriminator learns to distinguish between real and synthetic samples. As training progresses, the generator seeks to improve its ability to generate realistic samples by minimizing the discriminator's ability to differentiate between real and synthetic samples. Concurrently, the discriminator adapts to distinguish between real and synthetic samples more effectively. This adversarial interplay between the generator and discriminator networks culminates in the convergence of the GAN, wherein the generator produces high-fidelity synthetic data samples that closely resemble real samples.

## 3.3 Applications of GANs in Data Generation

GANs have found widespread applications across various domains, including computer vision, natural language processing, and biomedical imaging. In computer vision, GANs are utilized for image synthesis, style transfer, and image-to-image translation tasks. In natural language processing, GANs are employed for text generation, language translation, and dialogue generation. Moreover, GANs have been applied to generate synthetic medical images for diagnostic purposes and augment training datasets in healthcare.

## 3.4 Challenges and Limitations

Despite their remarkable capabilities, GANs are subject to several challenges and limitations. Training GANs requires careful hyperparameter tuning and stabilization techniques to prevent mode collapse and ensure convergence. Moreover, GANs are susceptible to generating samples that exhibit artifacts or biases present in the training data. Additionally, evaluating the quality of generated samples and ensuring diversity and coverage of the underlying data distribution remain ongoing challenges in GAN-based data generation.

## 4. Variational Autoencoders (VAEs)

Variational Autoencoders (VAEs) represent a class of generative models that combine elements of both autoencoders and probabilistic latent variable models. Proposed by Diederik P. Kingma and Max Welling in 2013, VAEs aim to learn a latent representation of input data while simultaneously generating new data samples. Unlike traditional autoencoders, which learn a deterministic mapping from input data to latent space, VAEs learn a probabilistic mapping that enables the generation of diverse and realistic data samples.

## 4.1 Architecture of VAEs

The architecture of a VAE consists of two interconnected neural networks: an encoder and a decoder. The encoder network maps input data samples to a latent space, where each point represents a latent representation of the input data. The decoder network, conversely, maps points in the latent space back to the input data space, generating synthetic data samples. Crucially, VAEs introduce a probabilistic component in the latent space, wherein each point represents a distribution rather than a single point. This probabilistic formulation enables the generation of diverse data samples by sampling from the learned latent space.

## 4.2 Training Process

The training process of a VAE involves maximizing the evidence lower bound (ELBO), a variational approximation to the true likelihood of the data. This entails optimizing both the reconstruction loss, which measures the fidelity of the reconstructed data samples, and the Kullback-Leibler (KL) divergence, which regularizes the distribution of latent representations. During training, the encoder network learns to encode input data samples into meaningful latent representations, while the decoder network learns to reconstruct input data samples from sampled points in the latent space. By jointly optimizing the encoder and decoder networks, VAEs learn to generate diverse and realistic data samples that closely resemble the training data distribution.

## 4.3 Applications of VAEs in Data Generation

VAEs have been applied to various data generation tasks, including image synthesis, molecular design, and anomaly detection. In image synthesis, VAEs are utilized to generate realistic images from random latent vectors, enabling applications such as image completion and style transfer. In molecular design, VAEs are employed to generate novel chemical compounds with desired properties, facilitating drug discovery and materials science. Moreover, VAEs have been utilized for anomaly detection by learning the normal data distribution and identifying deviations from this distribution.

### 4.4 Advantages and Limitations

VAEs offer several advantages over traditional generative models, including the ability to generate diverse and realistic data samples and the interpretability of latent representations. By learning a continuous latent space, VAEs facilitate smooth interpolation between data samples and enable fine-grained control over generated outputs. However, VAEs are subject to limitations such as blurry reconstructions and mode collapse, wherein the model fails to capture all modes of the data distribution. Additionally, ensuring the quality and diversity of generated samples remains a challenge in VAE-based data generation.

## 5. Recurrent Neural Networks (RNNs)

Recurrent Neural Networks (RNNs) represent a class of neural network architectures designed for processing sequential data. Unlike feedforward neural networks, which operate on fixedsize input vectors, RNNs can process input sequences of variable length. This makes RNNs well-suited for tasks such as language modelling, time series prediction, and sequence generation.

## 5.1 Architecture of RNNs

The architecture of an RNN consists of recurrent connections that enable the network to maintain a memory of previous inputs. At each time step, the RNN takes an input vector and a hidden state vector as input and produces an output vector and an updated hidden state vector. The hidden state vector captures information about previous inputs, enabling the network to model sequential dependencies within the input data. Crucially, RNNs can be unfolded over time to process input sequences of arbitrary length, making them suitable for tasks requiring temporal modelling.

## 5.2 Training Process

The training process of an RNN involves backpropagation through time (BPTT), wherein the gradients of the loss function are propagated backward through the unfolded network. During training, the network learns to update its parameters to minimize the discrepancy between predicted and ground truth outputs. By iteratively adjusting its parameters using gradient descent optimization, the RNN learns to model the underlying patterns and dependencies within the input data.

## 5.3 Applications of RNNs in Sequential Data Generation

RNNs have found widespread applications in generating sequential data, such as text, music, and time series data. In natural language processing, RNNs are utilized for tasks such as language modelling, text generation, and machine translation. By learning the statistical properties of language from large corpora of text data, RNNs can generate coherent and contextually relevant text samples. Moreover, RNNs have been applied to generate music compositions, where the network learns to capture musical patterns and structures from existing compositions and generate new musical sequences.

## 5.4 Challenges and Future Directions

Despite their efficacy in generating sequential data, RNNs are subject to challenges such as vanishing gradients and difficulty in capturing long-range dependencies. To address these challenges, researchers have proposed various enhancements to RNN architectures, such as Long Short-Term Memory (LSTM) networks and Gated Recurrent Units (GRUs). Additionally, future research directions include exploring novel architectures and training techniques for improving the quality and diversity of generated sequences.

## 6. Transformer Models

Transformer Models represent a class of neural network architectures introduced by Vaswani et al. in 2017 for sequence-to-sequence tasks, such as machine translation and language modelling. Unlike traditional RNN-based architectures, which rely on recurrent connections to capture sequential dependencies, Transformer Models leverage self-attention mechanisms to model long-range dependencies within input sequences. This enables Transformer Models to achieve parallelization and scalability, making them well-suited for processing large-scale datasets.

## 6.1 Architecture of Transformer Models

The architecture of a Transformer Model consists of an encoder and a decoder, each composed of multiple layers of self-attention and feedforward neural networks. The encoder takes an input sequence and processes it through multiple self-attention layers, wherein each token attends to all other tokens in the sequence to capture contextual information. Similarly, the decoder generates an output sequence by attending to the encoder's output and previous decoder states. By leveraging self-attention mechanisms, Transformer Models can capture complex relationships within input sequences and generate coherent outputs.

### 6.2 Training Process

The training process of a Transformer Model involves optimizing the parameters of both the encoder and decoder networks using gradient descent optimization. During training, the model learns to minimize the discrepancy between predicted and ground truth outputs using techniques such as teacher forcing and scheduled sampling. By iteratively updating its parameters based on the gradient of the loss function, the Transformer Model learns to generate accurate and contextually relevant output sequences.

## 6.3 Applications of Transformer Models in Text Generation

Transformer Models have been widely applied in natural language processing tasks, including text generation, language translation, and dialogue generation. In text generation, Transformer Models such as OpenAI's GPT series are capable of generating coherent and contextually relevant text based on input prompts. These models learn to capture semantic relationships and syntactic structures from large corpora of text data, enabling them to generate human-like text samples across various domains and styles.

## 6.4 Ethical Considerations and Biases

Despite their impressive capabilities, Transformer Models are susceptible to biases present in the training data,

which can manifest in generated outputs. Biases in language, such as gender stereotypes or cultural prejudices, can inadvertently propagate through generated text samples, potentially perpetuating harmful stereotypes and misinformation. Addressing these ethical considerations requires careful curation of training data, development of bias mitigation techniques, and ongoing monitoring of model outputs.

## 7. Domain-Specific Techniques

### 7.1 Procedural Generation in Computer Graphics

Procedural generation techniques are commonly employed in computer graphics to generate synthetic images, textures, and 3D models. By defining procedural rules or algorithms, researchers can generate infinite variations of virtual environments, landscapes, and characters. Procedural generation offers scalability and flexibility in content creation, enabling the generation of diverse and realistic virtual worlds.

## 7.2 Simulation-based Data Generation

Simulation-based data generation involves modelling complex systems or processes using computational simulations and generating synthetic data based on these simulations. In domains such as physics, biology, and economics, simulation-based techniques enable researchers to explore hypothetical scenarios, conduct what-if analyses, and generate synthetic data for training and testing machine learning models. By simulating realistic environments and interactions, researchers can generate synthetic data that closely resembles real-world observations.

## 7.3 Applications in Healthcare, Finance, and Other Domains

Domain-specific techniques for data generation have found applications across various domains,

including healthcare, finance, and transportation. In healthcare, synthetic data generation enables the generation of patient data for training medical imaging models, drug discovery, and disease prediction. Similarly, in finance, synthetic data can be used to simulate financial transactions, forecast market trends, and develop algorithmic trading strategies. Moreover, in transportation, synthetic data generation facilitates the simulation of traffic patterns, vehicle dynamics, and pedestrian behaviour for urban planning and autonomous vehicle development.

## 7.4 Challenges and Opportunities

Despite their potential benefits, domain-specific techniques for data generation are subject to challenges such as model fidelity, scalability, and computational complexity. Developing accurate simulations that capture the nuances of realworld phenomena requires domain expertise and careful validation against empirical data. Additionally, ensuring the privacy and security of generated data, especially in sensitive domains such as healthcare and finance, remains a critical consideration.

## 8. Evaluation of Synthetic Data

#### 8.1 Metrics for Evaluating Synthetic Data Quality

Evaluating the quality of synthetic data poses a unique set of challenges, as it involves assessing the fidelity, diversity, and coverage of generated samples. Common metrics for evaluating synthetic data quality include similarity measures, such as cosine similarity or Wasserstein distance, which quantify the similarity between generated and real data distributions. Additionally, diversity metrics, such as inception score or Frechet Inception Distance (FID), assess the diversity of generated samples relative to the training data distribution.

## 8.2 Benchmarking Against Real Data

Benchmarking synthetic data against real data is essential for assessing its utility and validity for downstream tasks. By comparing statistical properties and performance metrics on tasks such as classification or regression, researchers can evaluate the efficacy of synthetic data for training and evaluating machine learning models. Furthermore, conducting user studies and expert evaluations can provide qualitative insights into the realism and usefulness of synthetic data in specific domains.

### 8.3 Addressing Biases and Limitations

Synthetic data generation is susceptible to biases and limitations inherent in the training data and generative models. Biases present in the training data can manifest in generated samples, potentially propagating harmful stereotypes or misinformation. Moreover, limitations in the generative models, such as mode collapse or lack of diversity, can hinder the generalization and applicability of synthetic data. Addressing these biases and limitations requires careful curation of training data, development of bias mitigation techniques, and continuous monitoring and refinement of generative models.

## 9. Privacy-Preserving Data Generation

## 9.1 Differential Privacy Techniques

Differential privacy techniques offer a principled approach to privacy-preserving data generation by introducing noise or perturbations to data samples to prevent the disclosure of sensitive information. By ensuring that the presence or absence of individual data samples does not significantly impact the output of a generative model, differential privacy techniques provide strong privacy guarantees while enabling the generation of realistic synthetic data.

## 9.2 Federated Learning for Distributed Data Generation

Federated learning enables privacy-preserving data generation by training generative models on distributed data sources without sharing raw data. By leveraging decentralized computation and model aggregation techniques, federated learning enables the collaborative training of generative models while preserving the privacy and security of individual data sources. This approach is particularly well-suited for applications in healthcare, finance, and other sensitive domains where data privacy is paramount.

## 9.3 Secure Multiparty Computation

Secure multiparty computation (MPC) techniques enable privacy-preserving data generation by allowing multiple parties to jointly compute a function over their private inputs without revealing sensitive information. By encrypting data inputs and performing computations in a secure and distributed manner, MPC techniques enable the generation of synthetic data while preserving the privacy and confidentiality of individual data sources. This approach is applicable to scenarios where data sharing is prohibited or restricted by privacy regulations.

### 9.4 Legal and Regulatory Considerations

Privacy-preserving data generation techniques must comply with legal and regulatory requirements governing data privacy and security, such as the General Data Protection Regulation (GDPR) in the European Union and the Health Insurance Portability and Accountability Act (HIPAA) in the United States. Adherence to these regulations entails ensuring the confidentiality, integrity, and availability of generated data, as well as obtaining informed consent from data subjects where applicable. Moreover, transparent communication and accountability in data generation processes are essential for building trust and fostering ethical practices.

## 10. Future Directions and Emerging Trends

### 10.1 Advancements in AI for Data Generation

Advancements in AI for data generation continue to push the boundaries of what is possible, with ongoing research in areas such as self-supervised learning, meta-learning, and reinforcement learning. Self-supervised learning techniques enable generative models to learn from unlabelled data by leveraging auxiliary tasks or pretext tasks, thereby reducing the reliance on annotated datasets. Similarly, meta-learning algorithms enable generative models to adapt to new tasks or domains with minimal supervision, facilitating rapid deployment and customization of data generation models. Furthermore, reinforcement learning techniques enable generative models to optimize for diverse objectives, such as sample diversity, novelty, and fairness, thereby enhancing the quality and utility of generated data.

### 10.2 Multimodal Data Generation

Multimodal data generation, which involves synthesizing data samples across multiple modalities, such as images, text, and audio, presents new opportunities and challenges in AI research. By learning joint representations of different modalities, generative models can generate coherent and multimodal outputs that capture the complexity of real-world interactions. Applications of multimodal data generation include image captioning, cross-modal retrieval, and multimodal dialogue generation. However, generating high-quality multimodal data requires addressing challenges such as heterogeneity, alignment, and coherence across modalities.

### 10.3 Integrating Domain Knowledge

Integrating domain knowledge into generative models offers a promising avenue for improving the realism and utility of generated data. By incorporating domain-specific constraints, rules, or priors into generative models, researchers can ensure that generated samples adhere to domain-specific characteristics and constraints. This approach is particularly relevant in domains such as healthcare, finance, and engineering, where domain expertise plays a crucial role in data generation and interpretation. Moreover, integrating domain knowledge enables the development of interpretable and explainable generative models, thereby enhancing trust and transparency in AI systems.

### 10.4 Addressing Ethical Concerns and Societal Impacts

Addressing ethical concerns and societal impacts is paramount in the development and deployment of AI-driven data generation techniques. Ethical considerations, such as fairness, transparency, and accountability, must be carefully considered throughout the data generation lifecycle, from data collection and modelling to deployment and evaluation. Moreover, fostering interdisciplinary collaboration and engaging stakeholders, including policymakers, industry experts, and community representatives, is essential for addressing societal concerns and ensuring that AI-driven data generation benefits diverse stakeholders.

## 11. Conclusion

In summary, data generation with artificial intelligence offers a powerful and versatile approach to augmenting existing datasets, mitigating privacy concerns, and addressing class imbalances. By leveraging sophisticated algorithms such as GANs, VAEs, RNNs, and Transformer Models, researchers can generate synthetic data samples that closely resemble real-world observations across various domains and modalities. Moreover, emerging trends such as privacy-preserving data generation and multimodal data generation present new opportunities and challenges for AI research and applications.

### 11.1 Implications for Research and Practice

The advancements in data generation with artificial intelligence have far-reaching implications for research, industry, and society at large. In research, continued exploration of novel generative models, training techniques, and evaluation metrics is essential for advancing the state-of-the-art in data generation. In industry, AI-driven data generation enables the development of innovative applications and services across diverse domains, from healthcare and finance to entertainment and education. Moreover, in society, ethical considerations and societal impacts must guide the responsible development and deployment of AI-driven data generation techniques, ensuring that they benefit individuals and communities while minimizing potential harms.

## 11.2 Future Research Directions

Looking ahead, future research directions in data generation with artificial intelligence include advancing privacy-preserving techniques, enhancing multimodal capabilities, and integrating domain knowledge into generative models. Moreover, addressing ethical concerns and societal impacts, such as bias mitigation, fairness, and transparency, remains a pressing priority for the AI research community. By fostering interdisciplinary collaboration and engaging stakeholders, researchers can collectively contribute to the responsible and equitable development of AI-driven data generation techniques.

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## 4. Arsenic laden drinking water treatment: A review

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#### Abstract

Arsenic is typically found in natural waters in the oxidation states +III (arsenic) and +V (arsenate). Removing As (III) poses a more significant challenge than As (V) removal. Thus, As (III) must first be oxidized to As (V) before removal. This oxidation process is slow in the existence of pure oxygen or air but can be accelerated by various agents such as chlorine dioxide, hypochlorite, ozone, chlorine, and H2O2. Sophisticated oxidation techniques or the presence of sands coated with manganese oxide can also facilitate the oxidation of As (III). Different methods can be employed to eliminate arsenic from water, including softening the water or coprecipitating it with Fe (OH)3 and MnO2. Fixed-bed filters have proven effective in removing arsenic, and various sorbents such as activated alumina, FeOOH, granular activated carbon, ferruginous manganese ore, or natural zeolites have been investigated for their arsenic removal capabilities. Other elimination techniques include electrocoagulation, anion exchange, and membrane filtration using reverse osmosis, nanofiltration, or ultrafiltration.

Keywords: Adsorption, Coprecipitation, Ion Exchange, Membrane Process.

### 1. Introduction

The manifestation of arsenic poisoning, characterized by various signs and symptoms, is closely associated with elevated arsenic levels in drinking water, particularly prevalent in underdeveloped nations where millions are at acute risk. However, groundwater contamination with arsenic is not limited to underdeveloped regions. According to estimates by the US EPA, approximately 13 million Americans consume water containing more than 10 µg/L of arsenic. The US Geological Survey reports that out of the 54,000 public water supplies in the US, 14% surpass 5 µg/L, 8% surpass 10 µg/L, 3% surpass 20 µg/L, and 1% surpass 50 µg/L of arsenic.

Studies by Welch et al. indicate that around 10% of water samples in the United States surpass an arsenic concentration of 10  $\mu$ g/L, with over 13% exceeding 5  $\mu$ g/L. The expenses associated with producing drinking water containing lesser than 10  $\mu$ g/L arsenic are substantial, estimated by AWWARF and USEPA to range from \$102 million to \$550 million annually.

Extensive research has fixated on methods for oxidizing As (III) and developing and optimizing arsenic removal technologies. Available technologies include coprecipitation, adsorption onto various solids, membrane processes, electrocoagulation, and ion exchange. Reviews by Korte, Fernando and Nriagu discuss the concentration of As (III) in the environment, conditions affecting its mobility and fixation, arsenic removal technologies, health effects, and environmental impacts.

While community-level removal technologies are well-developed, they often come with a high cost. Hence, recent research has emphasized the development of affordable and user-friendly removal technologies, especially for regionalized use in rural areas of developing countries. Commonly used technologies in these regions include coagulation-precipitation, oxidation, and sorption onto activated alumina, iron oxide-coated materials, and activated carbon. Although membrane technologies have proven effective, they are often impractical for developing countries. Other strategies to reduce arsenic in drinking water include using shallow hand-dug wells known to be arsenic-free, tapping deeper aquifers free of arsenic, treating rainfall if there is enough rainfall throughout the year, and installing piped water supplies. This study discusses methodologies for As (III) oxidation and arsenic removal technologies in drinking water treatment, as well as point-of-use devices tested for usage in developing countries dealing with high quantities of arsenic in drinking water.

## 2. Materials and Methods

#### 2.1 Source of Water

The Waikato River, a significant supply of drinking water in New Zealand, has arsenic levels that range from roughly 10 µg/L at its source (Lake Taupo) to 30–60 µg/L as a result of both naturally occurring and artificial geothermal discharges. Three drinking water sources—Hamilton City, Rural, and Lake—were used for this investigation. All three used aluminium-based coagulation and drew water of similar quality, with duplicate samples taken on various days within the same week. The higher pH found at Lake Karapiro is the most prominent variation in water quality.

While Lake Karapiro gets its water from an artificial lake created on the river, Hamilton City and Rural water systems get their water from the river's flow. The Waikato River produces eight hydroelectric lakes, the latest of which is Lake Karapiro, which has a 7.7 km<sup>2</sup> area and a 2.8-day retention time (as of 1979).

About 100,000 people are served by the water supply in Hamilton City, while smaller towns of 3,000 and 10,000 people are served by Lake Karapiro and Rural, respectively. In Lake Karapiro and Hamilton City, alum is the coagulant of choice; in Rural areas, polyaluminium chloride is employed. A synthetic flocculant assist is utilized in all three treatment plants.

After filtering, Lake Karapiro's pH levels are rapidly adjusted, going from about pH 7 to 8.0–8.5 in the winter and pH 7.5 in the summer. Similarly, Hamilton City modifies its pH after filtering, going from 6.8 to 8.0. For every treatment plant, there were five assigned sampling locations: the source water, the first stage of coagulation (quick mix micro-floc production), the post-flocculation/clarification stage (macro-floc development), the post-filtration stage, and the final chlorination stage.

Twice in the summer and winter, samples were taken to record changes in the composition, flow, and demand for treated water in rivers. At treatment plants and sample sites, the following parameters were measured: total arsenic concentrations, soluble arsenic, As (V) and As (III), and arsenic bound to natural organic matter (OM).

ICP-MS analysis of acid-preserved samples was used to measure total arsenic, and field-filtered acid-preserved samples (0.45 µm) were used to measure soluble arsenic. Field-filtered samples run through an anion exchange column yielded soluble As (III). Dialysis against Milli-Q water was used to evaluate the amount of NOM-bound arsenic. Outside the bag, OM-bound arsenic was engaged, whereas inorganic arsenic achieved equilibrium both inside and outside the bag. Measuring UV showed that just 1% of UV-active OM could pass past the dialysis membrane. As previously mentioned, this procedure differs from that used for aluminum bound in alginate (Gregor et al., 1996).

### 3. Results

Figures 1 and 2 overview the arsenic forms and concentration changes during the three aluminum-coagulation treatment procedures. The averaged duplicate findings are shown for every sampling site. Considering the operational scale of a water treatment plant, the agreement in duplicate sample results is deemed reasonable. In the figure, each bar's height denotes the total arsenic content in the water, further categorized into soluble As (V) and soluble As (III).

At Hamilton City and Rural in the summer and Lake Karapiro in the winter, arsenic concentrations were lowered to 5 mg/L. Winter treatment yielded better per cent reductions and lower concentrations (51–3 mg/L) in treated water than summer treatment (3–10 mg/L) for all three treatment facilities. In the Waikato River, the concentration of arsenic overall was 1.5 times more in the summer than in the winter.

Excluding winter, arsenic was primarily soluble (85–100%) in all seasons. Furthermore, 90% or more of the soluble arsenic was present as soluble As (V) outside the Lake Karapiro summer. The treated water bore this exact prevalence of soluble arsenic. During treatment, the soluble As (V) component from the source water was transformed into a particulate form and primarily removed through settling. Through the course of the treatment procedure, soluble As (III) was mostly oxidized to As (V) during chlorination.

Unlike Hamilton City and Rural, soluble As (III) comprised a sizable amount (22%) of the Lake Karapiro summer source sample. The soluble component continued to exist in the succeeding stages of treatment, making it difficult for the treated water to reach the Maximum Allowable Value (MAV) of 0.01 mg/L. During treatment, this soluble arsenic's oxidation state changed in several ways. Due to pre-chlorination, it was first transformed to As (V) through rapid mixing. Between quick mixing and clarifier exit, it was then reduced to As (III), and at last, it was transformed back to soluble As (V) during chlorination and filtration. Regardless of the season, 4 mg/L of OM-arsenic was found in the source waters. The amount of total arsenic bound to NOM was lower in the summer due to a 1.5-fold increase in concentration over the winter, which was in line with the reduced OM content as measured by absorbance at 270 nm.

## 4. Discussions and Conclusion

Meeting the Maximum Allowable Value (MAV) for arsenic concentration in drinking water is crucial. In addition to removing particulate matter and organic substances (OM), aluminium coagulation plays a part in attenuating arsenic levels. The objective is to consistently lower arsenic concentrations to meet the tolerable standard for drinking water. In this study, two out of three treatment plants achieved this objective based on New Zealand's MAV of 10 µg/L, with the third plant achieving it for some months in the year. However, considering the potential for further lowering the acceptable concentration, as proposed in the USA, assessing whether existing treatment processes can achieve even better results is essential.

The Waikato River's arsenic comes from geothermal powerplant discharges and natural

geothermal sources, according to a comparison of arsenic fractionation in New Zealand and other water sources. As seen in this study, the Waikato River's seasonal fluctuations in arsenic concentrations are consistent with those stated at the Hamilton City intake in 1993 and 1994. The concentrations found in this investigation were consistent with those McLaren and Kim (1995) stated for the same period. It was noted that the predominant form of arsenic in the Waikato River is soluble, contrasting with findings from a recent national survey in the USA, where surface waters typically contain 23–54% particulate arsenic.

The Waikato River's high concentration of soluble arsenic may be related to the water's chemistry and geothermal origin. Mono-silicic acid, for example, has been shown to prevent arsenic from adhering to hydrous ferric oxide surfaces in geothermal well water. This same compound may prevent arsenic from adhering to iron-containing colloids and particles in the Waikato River.

The study's conclusions support earlier research showing that As (V) predominates in the Waikato River. In a lake environment like Lake Karapiro, the fraction of As (III) increases between summer and spring. This aligns with previous research, which attributes the increase to biologically induced sediment reduction and anoxic conditions with thermal stratification, which traps reduced As (III). As (III) is sustained in Lake Karapiro in summer due to an oxygen deficiency at depth. Anabaena, present in Waikato River water, is believed to reduce As (V) to As (III). Problems with odour and taste in the Lake Karapiro water supply discovered during summer sampling are linked to compounds produced by bacteria and algae, which suggest biological activity in the sediment or water.

	рН	Turbidity (NTU)	Absorbance at 270 nm <sup>a</sup>	Total arsenic (µg/L)
Hamilton city				
Summer	8.2, 7.6	3.0, 1.8	0.03, 0.03	27, 28
Winter	7.2, 7.5	1.5, 1.4	0.05, 0.05	18, 18
Pukerimu rural				
Summer	7.5, 7.3	1.0, 1.4	0.03, 0.02	29, 29
Winter	7.5, 7.5	0.7, 0.5	0.03, 0.04	16
Lake Karapiro				
Summer	8.4, 8.5	2.5, 2.1	0.03, 0.03	25, 28
Winter	8.7, 8.5	1.7, 1.0	0.04, 0.04	18, 18

Figure 1: Total Arsenic concentrations in water samples





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# 5. Effect of on-road parking on traffic stream characteristics for a mixed traffic condition

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### Abstract

With an emphasis on urban settings, this study explores the complex relationship between on-road parking and its effects on traffic flow parameters. The study looks into how on-road parking affects vehicle speed and traffic volume. It uses novel methodology that combines license plate-based parking surveys, spot speed data collection techniques, and traffic volume data collection techniques. The study establishes correlations between parking-related parameters (like parking volume, parking duration, and effective road width) and traffic parameters through meticulous data analysis. On-street parking was found to have significant effect on traffic dynamics and that the effective road width is a key factor in determining the maximum traffic speed. Regression analysis used in the study's model shows these variables to be significantly correlated. Effective road width exhibits a positive correlation. This study's findings emphasize the significant impact on urban traffic flow and safety of on-road parking. It emphasizes the necessity of careful urban planning and the formulation of parking policies to lessen negative effect of on-road parking. The suggested methodology provides useful insights for future research and urban policymakers attempting to balance the ease of parking with maintaining ideal traffic conditions.

Keywords: Urban congestion, on-road parking, traffic flow parameters, effective road width.

## 1. Introduction

On-road parking, also known as street parking, refers to the practice of parking vehicles along the side of a road or street. It's a common feature in urban and suburban areas where dedicated parking lots or garages may be limited. On-road parking can be either parallel, where vehicles are parked parallel to the direction of the road, or perpendicular, where vehicles are parked at a right angle to the road. It provides easy access to businesses, residences, and public spaces which make it very convenient for the customers or drivers. Beside the customers, on-road parking is also used by the drivers of commercial vehicle used for freight transport. Unfortunately, on-road parking is additionally connected with reduced mobility, reduced capacity of the road section and ultimately higher rate of accidents contrasted with streets of a similar classification without on-road parking (Greibe 2003; Pande and Abdel-Aty 2009). It is essential to recognize the causes for raised accident chances so as to configure proper countermeasures. Parked vehicles occupy significant portion of the road width which reduce pavement width, constraining to drive nearer to vehicles in the following lane or vehicles moving from opposite direction and forced to reduce their speed. Additionally, because of the narrow roads, lateral positions of the vehicles are shifted nearer to the center line which will ultimately increase the chances of accidents (Lewis-Evans, de Waard, and Brookhuis

2011). On road parking on the busy roads will cause stop-start condition for vehicles resulting in traffic congestion. Additionally, the unsettling influence brought about by drivers parking or un-parking in the road side increases the chances of accidents. In difficult urban conditions, while parking and un-parking, drivers must be very attentive to look for any passing vehicles in the adjoining lane or the presence of pedestrians in the vicinity. Parked vehicles can obstruct the visibility of the road, complicating the ability to observe pedestrian crossings. Without careful selection and regulation of on-street parking facilities and their locations, the road capacity would be significantly reduced.

## 2. Considerations and Polices

The Vehicles parked on-road generally uses hard shoulder or wide lane as parking spot. Parking facilities often include this as a component of their offerings. Clearly, it has favorable circumstances of being adaptable, space-sparing, and helpful compare to the off-road parking. However, on-road parking uses up pavement area, which effects the existing traffic condition. Cao, Yang, and Zuo (Cao, Yang, and Zuo 2017) estimated the impact of on-road parking on motorized and non-motorized vehicles. The study results identified on-road parking as a prominent factor effecting road capacity and safety. On-road parking essentially effect the speed dynamics of the vehicle by affecting the reaction time of the drivers. Mei and Chen (Mei and Chen 2012) defined two parameters to estimate traffic speed characteristics in terms of on-road parking. Space impact, the first parameter, is influenced by the types of on-road parking. The second parameter, time impact, influenced by the time required because of the parking maneuvers. Edquist, Rudin-Brown and Lenné (Edquist, Rudin-Brown, and Lenné 2012) conducted a study to explore how, on street parking and the visual complexity of the road environment impact travel speed and reaction time. Compared to very little on-road parking state, drivers said they felt more fatigued when driving in the full on-road parking condition. On-road parking slowed down the speed of ongoing vehicle and the vehicles are forced to move away from parked cars and turned into traffic. Drivers reacted more slowly to distant

objects, and took longer to react when confronted by an unexpected pedestrian. These conditions also influence the efficiency of signalized intersections. Xiaofei and CHEN (Xiaofei and CHEN 2011) found on-road parking maneuvers greatly affects the efficiency of intersection. Yousif and Purnawan (Yousif and Purnawan 2004) studied the traffic operation adjacent to an on-road parking facility. The primary factors being evaluated included the time taken to maneuver into or out of a parking spot and the willingness to accept gaps in traffic flow when exiting a parking space. The findings indicated that the layout of on-road parking significantly influences how drivers choose to park and exit parking spaces. If the on-road parking is totally prohibited, in that case it is required to provide additional off-road parking near the market places or business sector. In the city environment it is often not possible to allocate dedicated space for off-road parking. But offroad parking needs additional investments and resources. In some cases, material cost of setting the off-road parking can be minimized using recycled aggregate (Deb, Mazumdar, and Afre A. Rakesh 2024) but in the busy urban areas it would be difficult to find the space for off-road parking. Moreover, near the market area, freight modes also constitute a significant portion of the parked vehicles for the purpose of goods transportation in the adjacent market. Commercial drivers operating freight vehicles and engaging in various operations face significant challenges due to insufficient parking availability and, frequently, inadequate parking regulations that fail to account for the unique requirements of these vehicles. Jaller, Holguín-Veras and Hodge (Jaller et al. 2013) studied the parking issues faced by heavy trucks in New York. Freight trip generation estimates were used by them to propose a demand model for on-road parking. They deliberated on tactics for overseeing freight parking, considering the involvement of governmental bodies and other relevant organizations.

Although several previous literatures estimated the effect of on road parking facilities on traffic parameters and driver characteristics, but they fail to address the effect of on road parking in complex traffic scenarios which prevails in most of the Indian cities. Moreover, in most of the Indian cities no dedicated spaces are available for on-road parking, which force the drivers to park their vehicle beside the road occupying some portion of the effective road width. Therefore, in this regard it is very much important to study the effect of parking in such mixed traffic conditions. In most of the Indian cities, maximum areas in the city limit does not have any provisions for on-road parking facilities, yet drivers parked their vehicle on road occupying the effective road width. This significantly affect the traffic parameters and, in some cases, results in accidents and different safety hazards. It is very much required to improve this situation by regulating suitable parking policies for different urban sectors. In the urban public parking system, on-street parking is an essential component. A suitable parking charge structure helps to promote parking utilization and alleviate traffic congestion (Mei and Chen 2012). The issue of when to utilize on-road parking has sparked considerable controversy. However, research in this area has been insufficient, particularly concerning the interaction with mixed traffic flow. Parking restrictions can play an important role in persuading users of the private vehicles to switch to transit or other viable options. But such restrictions will not be helpful for the vehicles used for freight transportation. Because, in

most urban areas there do not exist any practical modal alternatives that could replace urban delivery trucks or freight transport modes. Therefore, it is needed to identify suitable policy for this type of vehicles. Moreover, if the on-road parking can be regulated, then it will enhance the revenue collection for the urban area. Therefore, in this study a detailed methodology is proposed to analyze parking related information in mixed traffic condition based on which a proper mechanism for parking regulations could be adopted.

## 3. Methodology

We devised a thorough approach to comprehend the impact of on-road parking on traffic flow dynamics. On-road parking has a direct impact on traffic flow, which affects the overall capacity of the road system. It is very important to know the type and nature of vehicles playing on the roadway before any further consideration to be made on design perspective of any city. Figure 1 shows the flow chart of the proposed methodology. The approach comprises two main components: Data Collection and Data Analysis.



Figure 1: Methodology flow chart

#### 3.1 Selection of Indicators Related to Parking

Parking volume, parking duration and effective road width are selected as indicators related to on-road parking. Parking accumulation is defined as the aggregate count of parked vehicles within a designated area at a particular point in time. The unit of parking accumulation is "number of vehicles parked". Parking accumulation is an important parameter which indicates total number of vehicles in different segment of time. Parking volume refers to the total count of vehicles parked within a specific area during a designated timeframe, excluding any duplicates. It represents the actual influx of vehicles into the area, recorded without considering repeated entries. The length of time a vehicle remains parked on the street is referred as parking duration. After getting the parking duration of each vehicle, the average parking duration for each vehicle categories can be identified. It will help to decide parking policy for different vehicle classes. Effective road width is defined as the actual width of the road when a considerable portion of the road width is occupied by parked vehicles.

#### 3.2 Selection of Suitable Traffic Stream Characteristics Affected by Parking

Traffic volume and speed are selected as parameters indicating the characteristics of the existing vehicular traffic. Traffic volume and speed can be counted by video-photographic survey adjacent to parking spot at predefined time interval. Traffic flow is the study of how vehicles, drivers, and infrastructure interact with one another. This infrastructure includes highways, signage, and traffic control devices.

Traffic behavior is intricate and nonlinear, arising from the interactions among numerous vehicles. Instead of adhering solely to mechanical laws, vehicles demonstrate complex behaviors due to the individual responses of human drivers. These behaviors include the formation of clusters and the propagation of shock waves, both forwards and backwards, which vary depending on the density of vehicles within a specific area. The condition of any traffic stream can be best described by analyzing speed; volume, density and the relationship exist between them. These parameters are connected with each other. Once traffic density reaches its peak flow rate and surpasses the optimal level, the flow becomes unstable, leading to prolonged periods of stop-and-go driving even from minor disturbances. Calculations inside congested networks, on the other hand, are more difficult and require empirical investigations and extrapolations from real road figures. Speed is a quality assessment of travel. Speed in traffic flow is defined as the distance covered per unit time.

Mathematically speed or velocity v is given by,

v=d/t

Where,

*v* = speed in *m*/s *d* = distance traveled in meter in time t seconds

Speed varies in terms of space and time. Different speed parameters are used in traffic and parking study. In this study, spot speed data are collected from the adjoining lane of the traffic. The instantaneous speed of a vehicle at a specified section or location is termed as spot speed. Spot speed analyses are conducted to gauge the speed distribution within a traffic flow at a designated spot. Using an endoscope, pressure contact tubes, radar speedometer, direct timing procedure, or time-lapse photographic methods allows for the measurement of spot speed. By measuring the distance traveled by a vehicle between two frames of video pictures, one can calculate it using the speeds obtained.

#### 3.3 Data Collection

Data Collection for Spot Speed Data and Traffic Volume Data. To begin understanding the influence of on-street parking zones on driving behavior within a portion of a road, a survey was required. The survey also gave an opportunity to gather information that was deemed as essential for observing qualitative affects and creating mathematical models to quantify consequences of speed. No survey technique has been utilized or created to accomplish the aforementioned goals, according to a thorough examination of the pertinent literature. As a result, a novel observational survey methodology was devised. A sample size of at least 50 and ideally 100 cars is typically acquired for a spot speed study at a chosen site. Traffic counts are often undertaken on a weekday barring Monday and Friday. Traffic counts performed during a Monday morning or a Friday peak time may reveal abnormally high volumes and are not typically employed in the research. Spot speed data may be gathered in several ways, including using stopwatches, radar devices, pneumatic road tubes, and more.

But as the parking study requires both the speed and traffic volume data, therefore video photographic survey can be used in such type of cases. This method can be successfully used to obtain speed data and traffic volume data. A suitable length on the preferred road section should be selected. The either side of the selected road section should be marked with any bright color. A video camera along with a tripod stand should be placed on the side of the road such that both the distinct marks on the road section are visible to the video camera. Also, the chance of occurrence of error in this method is minimal.

As mixed traffic condition is considered, therefore, volume data will be collected in terms of Passenger Car Unit (PCU) per hour. Under a certain set of road, traffic, and other conditions, the PCU may be used as an indicator of a vehicle class's relative space demand in comparison to that of a passenger car. One vehicle of a certain type is deemed equivalent to one passenger car with a PCU value of 1.0 if it alters the flow of traffic in the same way as one additional passenger car would. The PCU value of a vehicle class is determined by comparing the capacity of a roadway with only passenger cars to the capacity with vehicles solely from that class. The Indian Roads Congress (IRC) has suggested a set of PCU values for several vehicle categories that are typically seen on Indian urban roads, as outlined in Table 1.

3.3.1 Data collection for Parking Stream Related indicators. All parameters related to on-road parking can be collected by license plate method of survey. In this survey, every parking spot is observed at a constant interval of time and the license plate numbers of parked vehicles are noted down. By this survey, parking accumulation, category wise parking duration and parking volume data can be obtained. At the same time interval, the effective road width can be measured adjacent to the parking spot. With a shorter time interval, the likelihood of overlooking short-term parkers decreases, albeit at the expense of increased labor intensity associated with this method. As in the mixed traffic condition, different types of vehicles will be parked on road, therefore it is necessary to convert all the vehicles parked in a particular parking area to a single unit so that parking volume could be estimated for mixed traffic condition. This particular factor is termed as Equivalent Car Space (ECS) Conversion Factor. The adopted ECS value are shown in Table 2.

C1	Vahiala turna	Equivalent DCU factor			
different types of vehicle on urban roads					
Table 1: PCU values recommended by the IRC of					

SI.	Vehicle type	Equivalent PCU factor Percentage composition of vehicle type		
No.				
	Fast vehicles	5%	10% and above	
1	Motorized two wheelers	0.50	0.75	
2	Pick-up van, passen- ger car	1.0	1.0	
3	Auto-rickshaw	1.2	2.0	
4	LCV (Light Commercial vehicle)	1.4	2.0	
5	HCV (Heavy commercial vehicle)	2.2	3.7	
6	Tractor – Trailer unit	4.0	5.0	
	Slow vehicles			
7	Pedal cycle	0.4	0.5	
8	Cycle rickshaw	1.5	2.0	
9	Animal drawn vehicle	1.5	2.0	
10	Hand Cart	2.0	3.0	

Vehicle Type	Parking Slot Dimension	ECS
Passenger Car	5 m x 2 m	1.0
Motorized two wheeler	2 m x 1 m	0.2
Pedal cycle	2 m x 0.5 m	0.1
Autorickshaw	3 m x 1.5-2 m	0.6
Pedal rickshaw	2.5 m x 1 m	0.5
Bus	15m x 2.6 m	3.9
HCV	2.4m x 9m	2.2
LCV	2 m x 5m	1

#### 3.4 Data Analysis

After collecting the data, some preliminary analysis will be conducted to estimate the different parking characteristics. Then a relationship can be drawn between traffic characteristics and parking characteristics by a regression analysis. The postulated model for the regression analysis is given in Eq. 1.

$$y = a_1 x_1 + a_2 x_2 + a_3 x_2 \tag{1}$$

Where, y is traffic characteristics

 $x_1$ ,  $x_2$  and  $x_3$  are parking volume, parking duration and effective road width respectively. This equation indicates how traffic characteristics are affected by on-road parking. After that, average parking duration of different vehicle classes will be estimated from the collected data. Based on the analysis, some parking policy will be decided.

## 4. Study Area Selection

The study was conducted in various locations of Guwahati. Guwahati is an important business hub in North East India and it is largest city in this region. The city is spread across the bank of the mighty Brahmaputra River with an estimated area of 216 sq km. In different localities in Guwahati, specially near the market area, on-road parking was found to be a major issue. Maximum of the road sections are occupied the parked vehicles which create inconvenience for the adjoining traffic stream. For the survey purpose three important market areas are selected across the Guwahati city which are Narengi Market area (location 1), Bamunimoidan Market area (location 2), Six Mile Market are (Location 3).

## 5. Results and Discussions

The data collected from the three survey locations have been extracted and the analysis of the data is conducted. The survey was conducted on the locations on weekdays from 8am to 8pm. The survey data include parking related data as well as traffic stream characteristics. The extracted data along with some initial analysis is shown in Table 3. In Table 3, the average speed of the vehicles, indicates the average speed of all the vehicles running in the adjoining road in different time intervals. Traffic volume column indicate the traffic volume data for the vehicles running in the adjoining lane. Effective width of the road indicates the available width of the road after considerable portion of the road is occupied by the parked vehicles. Parking volume data is calculated based on the ECS values. Initially classified parked vehicle count survey was conducted, then the number of different vehicle classes have been converted to ECS/hr as per Table 2.

For location 1 (L1) it is found that average speed of the vehicles is lowest in the time interval of 10 to 11 am. Within this time, effective width of the adjoining road is also found to be lower and parking volume is found to be higher. It indicates that with the increase of vehicles on kerb, the effective width of the road decreases and average speed of the adjoining road decreases. Similarly, for location 2 and 3 similar situations are observed in the time interval of 10 to 11 am and 5 to 6 pm respectively. It indicates that with decreasing effective width, parking volume increases and speed in the adjoining road decreases. Table 3 indicates the variation of traffic volume with parking volume data. It indicates that with an increase in parking volume in some instances traffic volume decreases. But the relationship is not strong as in the previous instances, because traffic volume data is not only dependent on parking volume. There are other factors too, on which traffic volume depends. The average parking duration for different types of vehicles is shown in Table 3. From the physical survey of different locations, it was found that, driver of the commercial vehicles, in most of the cases, haphazardly parked the vehicle occupying a significant portion of the road width, which in turn minimize the effective road width. Moreover, it is found that, in some instances, personal four-wheeler also parked over the road section occupying significant portion of the road width. But in case of personal vehicles, the parking duration is found to be very less. So, they cause minimum disruption of the existing traffic stream.

Time	Location	Avg. Speed of the vehicles (Kmph)	Traffic volume (PCU/hr)	Effective width of the road (meter)	Average Parking Duration	Parking Volume (ECS/hr)
	L1	15.89	976.2	4.1	13.8	Parking Volume (ECS/hr)         32.2         37.7         16.6         21.1         59.3         13.8         34.4         54.6         37.8         19.1         22.3         28.6         29.8         43.1         33         23.5         36.3         16.5         20.7         25.4         22         21.4         54.5         22         17.3         32.5         17.3         21.9
8am-9am	L2	21.31	831.6	4.6	26.77	37.7
	L3	22	1007.6	5.97	22.01	16.6
	L1	14.82	1416.4	3.35	20.96	21.1
9am-10am	L2	19.9	969.6	4.2	20.72	59.3
	L3	19	1001.6	6.27	22.11	13.8
	L1	6.82	1392	3.25	27	34.4
10am-11am	L2	14.27	908	4.6	17.97	54.6
	L3	14.5	1012.4	6.05	25.26	Parking Volume (ECS/hr)         32.2         37.7         16.6         21.1         59.3         13.8         34.4         54.6         37.8         19.1         22.3         28.6         29.8         43.1         33         23.5         36.3         16.5         20.7         25.4         22         21.4         54.5         22         17.3         32.5         17.3         32.5         17.3         32.5         17.3         31.9         50.7         52.4         18.5         44.8         34.3
	L1	9.28	1264.4	3.85	44.49	19.1
11am-12pm	L2	14.87	1154	5.8	27.36	Parking Volume (ECS/hr)         32.2         37.7         16.6         21.1         59.3         13.8         34.4         54.6         37.8         19.1         22.3         28.6         29.8         43.1         33         23.5         36.3         16.5         20.7         25.4         22         21.4         54.5         22         17.3         32.5         17.3         32.5         17.3         32.5         17.3         32.5         17.3         32.5         17.3         32.5         17.3         32.5         17.3         21.9         50.7         52.4         18.5         44.8         34.3         13.3         32.8         40.3
	L3	14.1	1000.4	5.26	25.17	
	L1	9.85	1134	3.8	25.66	29.8
12pm-1pm	L2	14.31	983.2	4.3	26.12	43.1
	L3	22.04	920.4	4.4	27.5	33
	L1	13.05	1085.6	4.15	38.02	23.5
1pm-2pm	L2	23.33	1128.4	5.2	30.54	36.3
	L3	23.53	840	6.44	20.17	16.5
	L1	13.37	1054	4.7	39.46	16.5 20.7
2pm-3pm	L2	22.75	877.2	4.2	48.66	25.4
	L3	23.57	593.6	6.15	24.7	22
	L1	14.2	951.6	4.65	32.52	21.4
3pm-4pm	L2	20.25	972.4	5.2	30.95	54.5
	L3	20.14	722.8	6.47	15.5	36.3         16.5         20.7         25.4         22         21.4         54.5         22         17.3         32.5         17.3         24.0
	L1	12.26	1207.2	4.5	32.92	17.3
4pm-5pm	L2	18.46	1094.5	5.4	36.05	32.5
	L3	18.19	884.8	4.48	20.77	17.3
	L1	12.42	1104.8	3.65	27.37	21.9
5pm-6pm	L2	15.02	1082	5.8	31.82	50.7
	L3	13.97	946.8	4.37	21.02	52.4
	L1	14.19	892	3.52	19.25	18.5
6pm-7pm	L2	15.85	1058.8	6	32	44.8
	L3	14.44	718.8	4.66	22.07	34.3
	L1	14.63	893.2	3.9	23.42	13.3
7pm-8pm	L2	27.58	819	4.7	18.1	32.8
	L3	27.7	713.2	4	2.67	40.3

Table 3: Traffic stream characteristics and parking characteristics for location 1 in different time interval

## 6. Estimating Relationship Between Parking Parameters and Traffic Parameters

From the above discussion, it is clear that, traffic parameters like maximum speed of the passing vehicles and traffic volume have some relationship between parking parameters like effective width, parking volume and parking duration. But it is also evident from the above sections that the relationship between traffic volume and other parking parameters are not clear enough. In this regard, initially two separate models have been established for predicting the traffic volume and maximum traffic speed using the parking parameters. But from the analysis it is found that the regression coefficient for the relationship between traffic volume and parking parameters are very small. It indicates that the parking parameters considered in this study are not enough in predicting the traffic volume. Therefore, a mathematical model is formed displaying the relationship between maximum traffic speed and parking parameters. For the regression analysis, the data from all the locations were considered together.

The coefficient values for the regression analysis for are shown in Table 4. From the coefficient values it can be seen that the most important parameter is effective width of the road section. Coefficient values for parking volume and average parking duration are found to be negative. It indicates that if the parking volume and average parking duration increases, the maximum speed of the vehicles will decrease. The coefficient value for effective width of the road section is found to be positive. It indicates that if the effective width increases, the maximum speed of the vehicles will also increase. The R2 value for the relationship is found to be 0.75 which is an acceptable value. The relationship between the maximum traffic speed and the parking parameters could be drawn using the following equation:

Maximum traffic volume = 87.86-0.38 × Parking volume-0.35 × Average parking duration + 4.905 × Effective Width of the Road Section

 Table 4: Coefficient values for the regression analysis

Dependent variable	Independent variable	Coefficients	Sig.
	Constant	87.86	0.001
	Parking volume	-0.38	0.007
Maximum traffic	Average parking duration	-0.35	0.04
speed	Effective Width of the Road Section	4.905	0.01

## 7. Conclusions

Based on the available information, it can be concluded that on-road parking has a significant impact on traffic flow and safety. Parked vehicles occupy a significant portion of the road width, reducing the effective width of the road and forcing vehicles to drive closer to each other, which can increase the chances of accidents. On-road parking also causes stop-start conditions for the main traffic stream, resulting in traffic congestion. The duration of parking for personal vehicles is found to be very less, causing minimum disruption to the existing traffic stream. The study also highlights the need for careful selection and control of on-street parking facilities and their locations to avoid a decrease in the capacity of the road network. The study also suggests that video photographic survey can be used to obtain speed data and traffic volume data for parking studies.

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# 6. Efflorescence on damp wall: Its causes and its removal techniques

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#### Abstract

It is often seen on a building or residential structure that white powder accumulates at the corner of walls and also sometimes on the center of the walls. After inspection, it has been seen that it usually happens where there is continuous seepage of water from any other source to that wall. This leads to those conditions. Sometimes excess water seepage leads to greenish colour powder accumulation. And later we can see little plants growing around it if proper treatment is not done to it. This whole thing is due to efflorescence.

## 1. Introduction

Efflorescence is a white powdered layer which gets accumulates on a wall due to continuous seepage of water and soluble salts. Sometimes excess water and soluble salts give it a greenish colour and it also affects the other nearby walls.

So, for that, it's really important to get it treated and removed before it damages the whole structure of the building. This will cause a loss of strength in the building.

Generally, it happens during periods of warm weather like cold and rainy seasons. At that time the temperature is low. In the rainy season, there is continuous rain for two days, three days, and sometimes for a week. At that time it can't get treated which leads to the damage of the structure and hampering its strength. When it's left ignored for a longer period it often leads to deterioration of the structure or sometimes the whole building. It's in the hands of the engineer and the Architect who designs the structure to take care of such conditions and also have inspections at a regular interval of time.

## 2. Essential Reasons for Efflorescence to Happen

The main factors that lead to such conditions are:

• Water leakage

- Untreated leakage of water pipes in a building
- Water soluble salts
- Water may enter masonry walls due to some construction works nearby
- Water may enter due to heavy rainstorms
- As tiny droplets of water vapour due to humid conditions.

At the time of construction of the buildings or the structure, there might be some extra water deposited on the walls mortar, and plaster. And it has not been noticed and it disappeared after the construction. This leads to the pores which allow the rainwater during heavy rainfall to penetrate or infiltrate through it. This makes the wall wet at that point and water starts accumulating there as it doesn't get a way to go out.

There are soluble salts present in the water and also in the nearby surroundings which are also responsible for the efflorescence. The salts are usually like carbonates and sulphates of calcium, potassium, sodium, and magnesium. Also, the presence of chlorides and nitrates comes from groundwater. These Salts get penetrated the building easily with moisture. This further creates pores in the building. This affects the bricks, mortar, plaster, and also the timber. During construction, if these things are not kept in consideration, then it impacts the work of the contractor, the designer, and also the engineer who passed the design under his consideration. It also hampers their reputation and work ethics further. All this makes this important to understand the problem in the buildings due to the development of pores due to the contamination of salts.



Figure 1: Effloresce on the wall.



Figure 2: water leaking cause the bathroom's exterior wall to crack

## 3. Different Ways of Transport of Water and Salts in a Building

Building materials like the walls and fine and coarse aggregates absorb moisture. In this moisture, there are soluble salts that get inside it which further leads to chemical reactions with building materials and with the environment. Different salts come from different sources. It is not only through the transport of water but also some other sources. Like sulphates, nitrates and nitrites generally come from the atmosphere in urban areas. Nitrates can also be found in agricultural buildings like where plantations and vegetation are going on. It also sometimes comes from the seawater during the preparation of mortar which involves sand mainly. Efflorescence attacks all concrete and masonry walls through evaporation and hydrostatic pressure which is responsible for it to move. Calcium hydroxide which travels with the moisture reacts with the carbon dioxide available in the atmosphere resulting in calcium carbonate which gets deposited.

## 4. Prevention from the Formation of Eefflorescence

Many laboratory tests and also practical tests are done to get rid of efflorescence but none of them were effective. Depending on the mortar and concrete mix it can be avoided for a certain period. Once it gets infected it decreases the strength of that structure. If the efflorescence is treated at early stages then it's not so harmful. Like if the new masonry construction gets infected with efflorescence it is harmless and can be removed.

The reoccurrence of efflorescence or repetition of it is a major concern. In such cases, it needs to be operated and should be removed.

## 4.1 Preventive Measures should be taken to Stop the Formation of Efflorescence

A Good Drainage System should be provided at every end point of the building area so that there is no aggregation of water at a specific point which might lead to efflorescence. Constructing good mortar joints with no air voids in between which won't allow any water seepage. Ensuring curing is done properly at the time of construction. Not allowing any type of water entry through any pores of walls. By applying paints and distemper both inside and outside of the wall surface. Prevent the hardened concrete from getting exposed to moisture and atmospheric pressure conditions. Applying DPC (Damp Proof Courses) on every masonry wall of the buildings.

## 5. Steps for Removal of Efflorescence

**Applying Pressurized water:** By applying water at a huge pressure on the affected area of efflorescence will dissolve efflorescence quickly. Proper measures should be taken that after the application of water, it should be dried well.

**Using Brush:** Efflorescence can also be removed by applying a stiff bristle brush. If the result is not good or efflorescence is still there then use the scrubber to remove it. Also, a jet of high-pressure water can be used.

Using acid solutions: The application of different types of dilute acids on the affected area can also be helpful in the removal of efflorescence. Some of the acids that can be used are Hydrochloric acid and phosphoric acid.

Use of Vinegar: We can also use Vinegar on the affected area to remove the efflorescence because it's not as harmful as other chemicals and is easily available.

Coating the surface of the building: The application of the coating on the building surface will prevent it from any seepage of water and also vapor and other soluble salts. Coating should be done properly following different steps. Firstly, the building surface should be rinsed with water. Spray can be used for rinsing water on the surface. Secondly, apply the solution on the surface and wait for some time. Apply several coats of solution on the surface for better results. Thirdly rinse the surface with water again for the last time. Wipe the surface with a clean and dry cloth to clean the surface nicely.

**Application of DPC:** After cleansing the surface nicely apply DPC on the surface. This will be from any type of water entering the building.

Use of Sand Blasting technique: Removal of efflorescence using the Sand Blasting technique is an effective measure. However, it should be used carefully because it might damage the concrete structure of the building. Sand Blasting technique is a process in which very fine particles at a high velocity are sprayed on an affected surface which causes the removal of efflorescence.

## 6. Conclusion

The only effective treatment for efflorescence is to completely isolate the building from water. However, this isn't always realistic. The following are measures that can be helpful in specific situations. Brickwork that has efflorescence on it due to salts in the materials can be removed by carefully dry brushing and regularly washing the brickwork. Patches of salt on lone bricks in a structure with sufficient D.P.C. may also be eliminated. After each washing, the efflorescence's intensity lessens. Water-resistant surface treatments, such as silicon treatments, can be used to prevent water from penetrating stone structures. If the surface is devoid of fissures or cracks, it will work. Brickwork can likewise receive a similar treatment. Internal or external efflorescence in old buildings can be dangerous to those structures. The entry of water into the building can be identified as the cause. The D.P.C. is typically at fault or has not been provided at all. This has to be fixed correctly. Protecting the plinth should stop water from building up close to the walls. Other potential points of water entry should be thoroughly examined and fixed. Internal efflorescence can remove plaster from historic structures, leaving the bricks bare. Such surfaces should be restored with gypsum plaster after receiving a thick coat of bitumen-based substance. Buildings close to the ocean frequently experience issues with efflorescence and erosion. Adequate D.P.C. procedures are sufficient in these circumstances to stop erosion and efflorescence. It has been determined that replastering the deteriorated wall surface with a rich mix is insufficient. The wall should be sealed after a final sandblasting or acid washing to remove the efflorescence from the stonework. The efflorescence already suggests the possibility of soluble alkali sulphates in the wall and that these sulphates have pathways for migration to the surface. All that is left to do is stop moisture from penetrating the masonry and dissolving the sulphates. Efflorescence is a condition that can be managed and shouldn't be a concern in contemporary masonry. By paying attention to detail, using the right materials, and building well, it is possible to break the chain of circumstances that lead to efflorescence.

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# 7. Vibration mitigation using a series of hollow boreholes: A numerical investigation

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#### Abstract

The ground vibrations resulting from increased traffic, blasting, train operations, and construction-related activities can be largely attributed to the rapid growth of infrastructure. Rayleigh waves are the most predominant form of waves that result at the ground surface, thereby contributing to maximum dissipated energy in comparison to other wave types. The construction of a wave barrier can be considered an appropriate approach to effectively mitigate such ground-borne vibration. The present study aims to investigate the efficacy of a hollow borehole as a wave barrier for vibration isolation. Computational analysis has been undertaken to assess the effectiveness of hollow boreholes organized in a semi-circular configuration as a vibration barrier. The evaluation of the screening efficacy was conducted by assessing the Amplitude Reduction Factor (Arf) in hollow borehole conditions, considering different geometrical factors such as the distance between the pick-up point and the vibration source, borehole depth, and the load applied on the foundation. Empirical data suggests that the implementation of boreholes can be an effective method for mitigating ground-borne vibrations. A higher level of screening effectiveness is achieved when the normalized depth of the borehole (D)  $\geq 1$ .

Keywords: Active isolation, hollow borehole, Vibration screening, ABAQUS, FEM

## 1. Introduction

Ground vibrations are caused due to heavy traffic, blasting, movement of locomotives, and construction-related activities which resulted from the rapid growth of urbanization. Depending on the location of the source and amplitude of the vibration, people residing close to the vibration source suffer heavy setbacks in their standard of living. In certain situations, it is necessary to protect vulnerable structures or apparatus from external vibrations. In these circumstances, isolation from vibration proves to be essential. Rayleigh waves are the primary form of waves which contribute about 67% of the total wave energy dissipated (Woods 1968). These waves only travel for a limited distance beneath the surface of the earth. The rate at which these waves attenuate with distance is slower compared to that of body waves. Rayleigh waves are primarily responsible for structural damage and distress caused by vibration. Numerous researchers have proposed various vibration mitigation techniques. Trench barriers are a widely utilized vibration screening method. Open trenches (OT) and in-filled trenches (IFT) were proposed in various literature as methods for reducing vibrations. There are mainly two schemes of vibration isolation, namely active and passive screening. The active screening method involves the placement of barriers near the source of vibration to reduce the magnitude of these vibrations. However, the passive screening mechanism involves the placement of a barrier around the structure or equipment that necessitates protection from vibrations, irrespective of their origin.

OT or IFT are extensively employed due to their effectiveness in screening surface waves. In addition, it is important that the construction techniques employed are both practicable in terms of convenience in construction and cost-effectiveness. The efficacy of wave barriers is influenced by several factors, including soil characteristics, wave type, and the geometric properties of the barrier. To estimate screening efficiency, several researchers have conducted numerous numerical and experimental investigations to develop various novel techniques for vibration screening. The findings of Woods (1968) incorporated the outcomes of vibration screening conducted under conditions of both passive and active isolation. The study conducted by Jain and Soni (2007) suggests that the presence of adequate surface wave diffraction, interception, and scattering can result in the formation of an effective barrier. Subsequent experiments were carried out to examine different in-fill materials utilized in vibration barriers, including continuous geofoam-filled barriers (Alzawi and Hesham El Naggar 2011; Majumder and Ghosh 2014; Bose et al. 2018), intermittent geofoam barriers (Majumder, Ghosh, and Rajesh 2017a,b; Sarkar, Barman, and Bhowmik 2021), and trenches filled with soil bentonite slurry (Ahmad, Al-Hussain 1991). The Boundary Element Method (BEM) was used by Dasgupta, Beskos, and Vardoulakis (1990), Al-Hussaini and Ahmad (Al-Hussaini and Ahmad 1991), and Al-Hussaini and Ahmad (Al-Hussaini and Ahmad 1996) to analyze vibration screening. A finite element (FE) analysis was performed by Alzawi and Hesham El Naggar (2011) to examine the effectiveness of OT and IFT. Majumder, Ghosh, and Sathiyamoorthy (2017a,b) and Bose et al. (2018) have implemented the Finite Element Method (FEM) using PLAXIS in the research. It was observed that the depth of the trench normalized to Rayleigh wavelength  $(\lambda_{r})$  is one of the major influencing factors contributing to vibration isolation (Woods 1968; Dasgupta, Beskos, and Vardoulakis 1990; Al-Hussaini and Ahmad 1996; Majumder and Ghosh 2016). Also, it was found that the open trench is the most effective form of wave barrier as suggested by several researchers (Celebi and Schmid 2005; Sivakumar Babu et al. 2011; Saikia and Das 2014). The acoustic impedance  $(Z_i)$  is the lowest for air, which results in the maximum efficiency of open trenches. Acoustic impedance is the ratio of the product of Rayleigh wave

velocity and density of the material to that of the product of Rayleigh wave velocity and density of the surrounding soil (Barman, Sarkar, and Bhowmik 2021). However, due to ground instability problems or depth limitations, the in-filled trenches are found to be a more practical form of wave barrier (Al-Hussaini and Ahmad 1996; Ulgen and Toygar 2015). The trenches prove to be effective mostly for high frequency vibrations, whereas, the pile barriers can mitigate low frequency vibrations as they can go to a significant depth below the ground surface (Saikia 2014; Khan and Dasaka 2020). Numerous researchers proposed the use of a sequence of piles as an alternative vibration barrier that could provide improved screening effectiveness at low frequency vibrations (Gao et al. 2006; Cai, Ding, and Xu 2009). Woods, Barnett, and Sagesser (1974) and Sun et al. (2021) reported the use of a borehole for reducing ground-borne vibration. The enhancement of screening efficacy was observed as the depth and radius of the borehole were increased. With the decrease in the net spacing, screening effectiveness was increased gradually up to a certain limit. The study suggests that the optimal borehole radius should be between the range of 0.1to 0.15  $\lambda_{\rm c}$ . Additionally, it is recommended that the borehole depth should be 1  $\lambda$ , while the net distance between boreholes should be 0.1  $\lambda_{..}$ 

Woods (1968) investigated the propagation of surface waves in soils through open and circular trenches for active isolation, and open straight trenches for passive isolation. It was observed that in active isolation cases, a normalized minimum depth (D =  $d/\lambda_{z}$ ) of 0.6 was required for a trench to satisfy the amplitude reduction criteria of 0.25. Haupt (1995) investigated the vibration isolation efficiency of various types of barriers with a series of scaled model experiments in homogeneous, artificially densified sand. Concrete barriers, lighter barriers such as rows of boreholes, and open trenches were also considered. Dasgupta, Beskos, and Vardoulakis (1990) proposed a numerical methodology that is based on BEM to solve vibration isolation problems in three dimensions under plane strain conditions. Harmonic and transient dynamic disturbance has been considered for both active and passive vibration isolation cases in open and in-filled trenches. Ahmad and Al-Hussaini (Ahmad and Al-Hussaini 1991)

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conducted a series of parametric investigations utilizing the BENAS2D algorithm, a reliable two-dimensional BEM algorithm. These studies involved various factors including frequency, reduction zone area, trench dimension, trench position, Poisson's ratio, and characteristics of the in-fill material such as density, wave velocity, and damping. According to the study, the most significant amplitude reduction zone is to a distance of  $10\lambda$  from the vibration source. The significance of normalized depth (D) is crucial in the context of open trenches, but the importance of normalized width (W) is often negligible, especially in cases when the depth is small (D < 0.8). Both normalized depth and width are significant factors in the context of IFT. Kattis, Polyzos, and Beskos (1999)conducted a study to examine the effectiveness of open trenches, in-filled trenches, and a row of pile barriers (consisting of concrete and hollow piles) in mitigating vertical vibration. Gao et al. (2006) demonstrated that a single row of small cross-sectional piles can be equally effective as a trench. The authors proposed that the optimal normalized spacing for each pile is 0.1, whereas the optimal normalized spacing between two rows of piles is 0.15. Celebi and Schmid (2005) conducted a field experiment to investigate the effects of wave barriers, specifically trenches, on wave propagation and vibration isolation. The study aimed to examine the efficacy of wave barriers in mitigating motion amplitudes in IFT. The screening effectiveness of different isolation materials, including bentonite (softer), concrete (stiffer), and water was explored. The research findings indicate that IFT with softer materials exhibits more efficacy in terms of passive isolation compared to active isolation.

Also, Alzawi (2011) in his doctoral thesis, introduced a novel methodology involving both experimental and numerical investigation for mitigating vibrations by employing geofoam as a barrier material within an IFT. The efficacy of the barrier was shown to be higher when the value of D is more than or equal to 0.6. Saikia and Das (2014) employed a two-dimensional model that was developed using the PLAXIS 2D software. In the study, a dimensionless parameter was utilized to analyze and evaluate different trench dimensions. The findings indicate that an increase in the D value leads to a decrease in the amplitude reduction factors (Amx and Amy) in

both the x and y-directions, irrespective of the position or width. The effectiveness of vibration mitigation was seen through the implementation of a trench with a minimum depth of D =0.6. In the study conducted by Saikia (2014), a computational FE modelling approach was employed using PLAXIS 2D software. The research focused on dual trenches instead of single trenches due to limitations observed in the latter for small to medium surface wavelengths. Single trenches necessitated impractical depths for longer wavelength (low frequency) instances. The findings also indicate that there is a negative correlation between the shear wave velocity ratio and the Arf value, suggesting that a decrease in the former leads to a fall in the latter. Subsequently, a study conducted by Majumder and Ghosh (2014) stated that the performance of continuously filled geofoam is better than various rigid soil deposits. According to the findings of Mahdavisefat, Salehzadeh, and Heshmati (2018), it was observed that the isolation efficiency of a sand-rubber mixture (SRM) consisting of 30% sand is comparable to that of an open trench. Further, Sarkar, Barman, and Bhowmik (2021) conducted a numerical investigation on the efficacy of utilizing a composite IFT as a wave barrier for vibration screening. The in-fill materials utilized to achieve optimal screening efficacy of the barriers consisted of a mixture of EPS12 geofoam and sand-crumbed rubber, with a relative density of 35%. The study showed that the performance of the geofoam and sand-crumbed rubber-filled trench (GSFT) is comparable to that of EPS12 geofoam fill in the trench while outperforming the SRM-filled trench. Based on the findings of the research, a composite fill material consisting of an equal combination of geofoam and sand-crumbed rubber exhibited a screening efficiency ranging from 70% to 75%.

From the review of the previous literature available on vibration isolation using barriers, it was observed that there is a lack of three-dimensional numerical studies involving the use of a series of boreholes as a wave barrier. Thus, the present study is aimed at conducting a 3D numerical study using a single row of the borehole placed in a semi-circular configuration around a machine foundation to investigate the vibration isolation efficiency. The study also involves the parametric investigation of the various influencing factors that regulate the vibration isolation effectiveness of the boreholes as wave barriers like depth of the borehole, distance of the pick-up sites from the source, and the effect of varying load intensities applied on the foundation. However, the utilization of in-filled boreholes for vibration mitigation is beyond the scope of the present study and can be carried out in the future course of the study.

## 2. Definition of the Problem

#### 2.1 Methodology

The numerical simulation is conducted in order to investigate the characteristics and performance of the hollow boreholes as wave barriers. A square foundation is subjected to a uniform harmonic load with a constant amplitude, which varies in frequency. The frequency considered for the load is noted at 30 Hz. The square foundation is assumed to be supported by a uniform and linearly elastic soil medium. The boreholes placed in a semi-circular configuration have been placed at a certain distance from the center of the foundation. The dimensions of the model are normalized with the Rayleigh wavelength ( $\lambda$ ). The study focuses on the investigation of hollow boreholes which are placed on the path of wave propagation. The vertical displacements are recorded at different pick-up locations along the vibration source. The determination of the efficacy of the trench barrier is ultimately achieved through the utilization of the amplitude reduction factor (Arf).

#### 2.2 Amplitude Reduction Factor (Arf)

The amplitude reduction factor (Arf) is a numerical measure that compares the vertical amplitudes observed at a specific pick-up point in a model, taking into account the presence of a barrier, to those observed without considering the barrier (Woods 1968; Al-Hussaini and Ahmad 1996). In terms of Arf, the determination of vibration screening for a specific pick-up point has been established [1] and can be represented by Equation 1.

$$\operatorname{Arf} = \frac{V_0}{V_T} \tag{1}$$

Where  $V_0$  is amplitude of vertical displacement for without borehole and  $V_T$  is amplitude of vertical displacement with borehole.

The average amplitude reduction factor (AArf) is determined using Equation 2.

$$AArf = \frac{1}{n\lambda_r} \int_0^{n\lambda_r} Arf \, dx \tag{2}$$

The efficiency (Eff) of the borehole can be computed using Equation 3 [1].

$$Eff(\%) = (1 - AArf) \times 100$$
(3)

The lower the value of Arf, the higher is the efficiency of the barrier.

#### 2.3 Material Properties Determination

The soil characteristics in the surroundings are evaluated by the outcome of a variety of laboratory tests on undisturbed soil samples obtained from the location adjacent to the Centre for National Accreditation Board for Testing and Calibration Laboratory at the National Institute of Technology Silchar, Assam. In the context of numerical analysis using ABAQUS software, the soil is regarded as exhibiting linear elastic behaviour. The effect of groundwater table is not considered as it is assumed to be at greater depth. The velocities of the primary wave  $(V_p)$ , shear wave  $(V_s)$  and Rayleigh wave  $(V_R)$  have been determined through Equations 4, 5 and 6 respectively [29]. The soil parameters incorporated in the numerical model are presented in Table 1.

$$V_{P} = \sqrt{\frac{(1-\mu)E}{(1+\mu)(1-2\mu)\rho}}$$
(4)  
$$V_{S} = \sqrt{\frac{E}{2(1+\mu)\rho}}$$
(5)  
$$V_{R} = \left(\frac{0.87+1.12\mu}{1+\mu}\right)V_{S}$$
(6)

$$\lambda_r = \frac{V_R}{f} \tag{7}$$

where  $\mu$ ,  $\rho$  and f denote the Poisson's ratio, density and excitation frequency of soil medium.

 Table 1: Material properties

Property	Unit	Value
Unit weight (γ)	kN/m <sup>3</sup>	19.70
Water content (w)	%	17.68
Specific gravity (G <sub>s</sub> )	-	2.59
Cohesion (c <sub>u</sub> )	kN/m <sup>2</sup>	110.79

Friction angle ( $\phi$ )	(°)	28
Primary wave velocity (V <sub>P</sub> )	m/s	378.66
Shear wave velocity (V <sub>s</sub> )	m/s	182
Rayleigh wave velocity $(V_R)$	m/s	170.13
Shear modulus (G)	kN/m <sup>2</sup>	6.52104
Rayleigh wavelength $(\lambda_r)$	m	3.7
Poisson's ratio (µ)	-	0.35
Rayleigh wave coefficient (α)	-	1.0362
Rayleigh wave coefficient (β)	-	0.0007

Table 1: (Continued)

## 3. Numerical Investigation

A 3D FEM model was developed in ABAQUS to determine the screening efficiency of a single row of the hollow borehole.

#### 3.1 Geometrical Configuration of the Model

A circular geometry was considered for the analysis of the vibration isolation system. The radius of the geometry (soil) was set at 30 m, and the depth was considered 20 m. The vibration barriers in the form of boreholes are extended up to 3.7 m from the ground surface.

#### 3.2 Details of the Numerical Analysis Model

This study focuses on the machine foundation as the origin of vertical dynamic load intensity. The soil mass exhibited a non-linear elasto-plastic material feature. The barrier was positioned adjacent to the vibration source. Ground vibrations were detected at various locations near the source of vibration. The parameters l, d', and d represent the distance of the borehole from the source, the diameter, and the depth, respectively. x represents the distance from the pick-up point to the origin of vibration. The normalized borehole depth is represented by the symbol D ( $d/\lambda_2$ ). The borehole's normalized diameter, denoted as D'  $(d'/\lambda_i)$ , was determined to be 0.028. The borehole was located at a distance of 0.325 times the normalized distance of the trench barrier L  $(l/\lambda_{1})$  from the source site. Furthermore, X is the standardized measure of the distance between the pick-up spots and the source of vibration. The current numerical analysis utilized a loading resonance frequency of 30 Hz. The expected net normalized distance between the boreholes (S) was 0.08. The simulations were conducted under two conditions: with an open borehole and without a borehole. The Arf was estimated by measuring the peak vertical displacement at the pick-up locations situated at different distances from the vibration origin.



(a)



Figure1(a, b): FEM model of the soil mass with the row of boreholes

#### 3.3 Material Modelling

The soil characteristics employed in this finite element study are derived from the attributes of the indigenous soil. A range of laboratory and field studies were employed to assess the characteristics of the soil. The material qualities acquired are listed in Table 1. Rayleigh damping refers to the dissipation of energy in a physical system due to the viscous forces acting on it. Damping can occur due to the presence of a viscous media, friction, and the flexibility of the soil deposit. The soil has a damping ratio ranging from 4% to 6%. The damping ratio for soil deposits was considered to be 5% (Alzawi and El 2011; Barman, Sarkar, and Bhowmik 2021; Al-Hussaini, Ahmad, and Baker 2000). The mass and stiffness of the system are proportional to the Rayleigh damping which can be represented by the equation:

$$[C] = [M] + [K]$$
(8)

in which [C] = damping matrix of the given system; [M] = mass matrix of the given system; [K] = stiffness matrix of the given system;  $\alpha$  and  $\beta$  are the Rayleigh mass and stiffness coefficients. The determination of these coefficients involves the selection of the initial and secondary natural frequencies of the soil deposit. The coefficients of the Rayleigh wave are presented in Table 1. The modelling parameters utilized for analysis in ABAQUS are presented in Table 2.

Variables	Property
Mesh type	8-noded 3D brick element with reduced integration (C3D8R) and 8-noded 3D continuum infinite element (CIN3D8)
Meshing technique	Structured
Maximum time step increment $(\Delta t)$	0.001 s
Interaction between foundation and soil mass	Normal behaviour with hard contact
Interaction between soil mass and in-filled trench	Tie constraint
Total run time	1 s
Output	Vertical displacement with time

Table 2:	Abaqus	modelling	parameters
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#### 3.4 Analysis Procedure

The harmonic loading was studied using dynamic implicit analysis. The relationship given by Valliappan and Murti (1984) has been used to define the time step (t) of the dynamic analysis.

$$\Delta t \le \frac{Average \ element \ size}{Velocity \ of \ slowest \ propagating \ wave} \tag{9}$$

The numerical model has an average element size that was lower than 1/8th of the shortest wavelength, thereby satisfying Kramer's wave propagation condition (Kramer 1996). The analysis was conducted for a duration of 1 second, with a maximum time step increment of 0.001 seconds considered.

#### 4. Mesh Convergence

The meshing of the overall model is done in accordance with the results obtained from the mesh convergence study carried out on a model where the trench depth considered is 1  $\lambda_{r}$  and the frequency of excitation is assumed to be 30 Hz. For the convergence study, the meshing has been done to conform with various number of elements and finally, the peak displacements beyond the trench are noted at all the instances. The finer the meshing, more accurate the results. It can be found from Figure 2 that with the increase in number of elements, the values of peak displacements also increase. However, there is no significant increase in the value of peak displacements when the number of elements considered was 1,00,000 and above. Hence the meshing comprising of 1,22,796 elements has been considered for all the numerical models in ABAQUS software. Figure 1(a, b) depicts the meshed FEM model of the soil mass and the single row of hollow boreholes.



Figure 2: Peak displacement for different mesh sizes

## 5. Model Validation

The numerical models of the present study were validated with the other studies as well. The soil model with  $0.405 \lambda_r$  depth,  $0.1 \lambda_r$  diameter boreholes placed at a distance of  $0.5 \lambda_r$  was validated in accordance with the model derived from Sun et al. (2021). The results obtained showed a similar trend being followed by both the studies. The Arf values of the present study were found to follow a similar trend with the other study of the domain. The graphs showing the comparison between the two studies is demonstrated in Figure 3.



Figure 3: FEM model validation

### 6. Results and Discussion

The variation of Arf with different pick-up points (X = 0.1, 0.14, 0.19, 0.24, 0.29, 0.35, 0.42, 0.52, 0.61, 0.70, 0.88, 1.05, 1.41, and 2.1), different borehole depth (D = 0.65, 1, 1.2, and 1.4), different eccentricity (F = 9.11, 19.38, 29.67, and 48.55 kN) were observed in the present study. The vertical displacement at a specific pick-up site in the case of an open borehole was measured under barrier-free and barrier-containing conditions. A similar pattern was noted in both of the cases examined in the study. Figure 4 shows the vertical displacement vs. dynamic time plot for without barrier and with barrier cases. The amplitude of vibrations was found to be lower for with barrier case. Figures 5 and 6 illustrates the deformed FEM model.



Figure 4: Displacement vs. time plot



Figure 5: Contour diagram of the FEM model



Figure 6: Deformed mesh of the model

#### 6.1 Effect of Depth of Borehole

Figure 7 illustrates the relationship between the normalized borehole depth (D) and the variation of Arf. Four different depths were chosen as mentioned in the previous section. It can be observed that as the parameter D increases, there is a corresponding decrease in
the Arf value for cases involving open boreholes. Four different intensities of forces were applied on the foundation to assess the screening efficiency of the system. The Arf value shows an inverse correlation with the depth of the borehole. When the D was increased from 0.65 to 1.0, a dropdown in the Arf value was observed for all the load intensities. This implies that higher the depth of borehole, lower will be the Arf, the higher will be the screening efficiency. Beyond the normalized depth of 1, the change in the behaviour of the barrier in screening the vibrations is found to be significant. The maximum efficiency was observed when D 1.



Figure 7: AArf vs. normalized depth of borehole

# 6.2 Effect of Distance of Pick-up Points from Source

The effect of various normalized distance of pick-up points is studied for the different depth cases and their effects on Arf values were presented in graphical form as shown in Figures 8 and 9. A similar trend of decreasing order was observed for all the cases of study. At the borehole location, a sudden amplification zone was observed due to the scattering and reflection of waves at the boundary of the barrier. However, beyond the wave barrier, the Arf followed a decreasing trend. The lowest Arf values were obtained for the open borehole with D = 1. The Arf values reduced rapidly when the normalized distance was 0.25 to 0.5. However, after a normalized distance of 1, the change in Arf values observed is negligible.



Figure 8: Arf vs. normalized distance from source



Figure 9: Arf at different pick-up points for different depths of boreholes

#### 6.3 Effect of Varying Load Intensity

Figure 10 illustrates the relationship between the Arf value and the load intensity. The figure depicts the positive correlation of the Arf values with the load intensities. This implies that as the load applied on the foundation increases, the Arf values also increase, which shows a decrease in the screening effectiveness of the system. Also, Figure 11 demonstrates the change in Arf value for the different depths of boreholes considered in the study. A similar increasing trend was observed for all the cases. A significant increase of 20-30% in AArf was observed when the load applied was changed from around 10 kN to 50 kN.



Figure 10: AArf at different loading intensities



Figure 11: AArf vs. load applied for different depths of boreholes

# 7. Conclusions

A 3D numerical investigation was carried out a row of hollow boreholes placed in a semi-circular pattern around the machine foundation. Based on the various observations, the following conclusions were drawn from the results obtained:

- In the case of an open borehole, the efficacy improves as the depth increases 70–80% efficacy of borehole was observed at a normalized borehole depth (D) ≥ 1. As a result, it is determined that a depth of 1 λ<sub>r</sub> is optimal to attain the intended degree of screening efficacy.
- The screening efficiency was determined to be proportional to the distance between the site of pickup and the vibration source based on the parametric analysis. An amplification zone was observed near the barrier boundary due to the

scattering and reflection of waves at the borehole boundary. Due to which, the Arf value increases near the source of vibration. As the distance of pick-up point increases from the barrier, the Arf value reduces. However, beyond a distance of1  $\lambda$ , the decrease in Arf value is negligible.

• Also, with the increase in load applied on the foundation, the Arf value was observed to be increasing gradually. Therefore, the screening efficiency decreased with the increase in the loading intensity.

## 8. Acknowledgement

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# 8. A review on enhancing soil index properties through the addition of stone dust mix

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#### Abstract

The modern construction landscape faces unprecedented challenges due to rapid urbanization and industrial growth, necessitating innovative approaches to enhance soil index properties. This review critically examines diverse methodologies employed for soil improvement, ranging from traditional techniques to cutting-edge advancements, encapsulating the multidimensional nature of geotechnical engineering. In exploring traditional soil improvement methods, such as compaction and chemical stabilization, we lay the groundwork for a nuanced understanding of contemporary interventions. The spotlight then shifts to the utilization of industrial waste materials, including fly ash, slag, and stone dust, investigating their impact on crucial soil properties. Geosynthetics, encompassing geotextiles and geomembranes, emerge as versatile tools for soil enhancement, with recent research illuminating their efficacy. Bio-mediated techniques, influenced by microbial activities and vegetation, offer an ecologically sensitive avenue for soil improvement. The burgeoning field of nanotechnology contributes novel insights into the modification of soil index properties, promising transformative effects on geotechnical practices. Case studies and field applications underscore the real-world success of these methodologies across diverse environments. Environmental implications form a central theme, emphasizing sustainable soil improvement practices aligned with ecological conservation. Acknowledging challenges, the review envisions future directions, proposing interdisciplinary collaborations and emerging technologies to address evolving construction needs. This synthesis of methodologies and future considerations positions the review as a vital resource for researchers, engineers, and practitioners navigating the intricate landscape of soil improvement in the pursuit of resilient and sustainable infrastructure.

# 1. Introduction

In the rural context, where approximately half of the global population resides, the significance of roads cannot be overstated, as they serve as linchpins for economic, physical, social, and political development. Rural roads are pivotal in facilitating accessibility and mobility, influencing key aspects of rural life, including education, agriculture, and healthcare. Despite their paramount importance, an astonishing 85% of the 38.8 million kilometres of rural roads worldwide experience lower traffic volumes, averaging less than 1000 vehicles per day. Compounding this issue, 31% of the global rural population still resides more than 2 kilometres away from roads resilient to all weather conditions.

The Indian landscape is emblematic of these challenges, where the Rural Accessibility Index (RAI) stands at 61%, as reported by the World Bank in 2006. In response to this disparity, India launched the Pradhanmantri Gram Sadak Yojana (PMGSY) project in 2000, with an ambitious goal to connect 180,000 habitations, comprising 500 in plains and 250 in hills and tribal areas, with all-weather roads by 2015 (Mahent and Joshi 2015). This monumental endeavour, backed by a substantial budget of 33 billion US dollars, encompasses the construction of 372,000 kilometres of new roads and the upgrading of 370,000 kilometres of existing roads.

Crucial to the success of such extensive rural road projects is soil stabilization, an indispensable aspect of road and railway construction. Poor soil properties pose a formidable obstacle to construction suitability, necessitating enhancements in soil strength, California Bearing Ratio (CBR) values (Muley and Jain 2013), and reductions in permeability and compressibility. Diverse techniques, ranging from mechanical and chemical to electrical and thermal methods, are deployed based on project specifics, resource availability, and overall cost considerations.

This research delineates a focused exploration into the utilization of stone powder, an abundantly available industrial waste product, to ameliorate soil properties in the context of rural road development. The approach not only addresses the effective disposal of significant quantities of stone dust, an inevitable by-product comprising 20-25% of total production in crusher units but also champions sustainable construction practices.

# 2. Traditional Soil Improvement Techniques

This section provides a succinct examination of time-honoured soil improvement methods, encompassing compaction, chemical stabilization, and mechanical reinforcement. Understanding the foundations of traditional approaches serves as a backdrop for evaluating the efficacy of more modern interventions.

#### 2.1 Utilization of Industrial Waste Materials

At the forefront of this exploration lies an extensive review encompassing a myriad of studies dedicated to unravelling the potential of industrial waste materials in the realm of soil improvement. The spotlight is specifically directed towards the examination of materials like fly ash, slag, and stone dust—by-products of various industrial processes. These materials, often considered as waste, emerge as valuable assets in the domain of geotechnical engineering, with the capacity to significantly influence fundamental soil index properties (Bačić, Marčić, and Peršun 2017; Rama Subbarao et al. 2011).

Fly ash, a by-product of coal combustion in power plants, holds a prominent position

in this investigation. Its application as a soil amendment has been scrutinized across diverse contexts, with studies delving into its impact on crucial soil parameters (Kishor, Ghosh, and Kumar 2010; Shaheen, Hooda, and Tsadilas 2014; Joshi and Nagaraj 2021). Similarly, the inclusion of slag, a by-product of metal smelting, is under the microscope for its potential to alter soil characteristics (O'Connor et al. 2021; Qureshi, Mistry, and Patel 2015). The examination extends to stone dust, a residual material from crushing operations, which, though seemingly a by-product, emerges as a resourceful substance in soil improvement endeavours (Prasetia and Trihamdani 2024).

The core emphasis of these studies is on unravelling the intricate interactions between these industrial waste materials and key soil index properties. Parameters such as cohesion, shear strength, and compressibility, which play pivotal roles in determining the engineering feasibility of soils, are meticulously evaluated. The review scrutinizes the methodologies employed in these studies, shedding light on the varied approaches to application and the resultant effects on soil behaviour.

By comprehensively synthesizing findings from disparate studies, this review aims to distil a nuanced understanding of the efficacy of industrial waste materials in soil improvement. It aspires to delineate not only the successes but also the challenges and limitations associated with these materials, thereby providing a comprehensive resource for researchers, engineers, and practitioners navigating the intricate terrain of sustainable geotechnical practices.

#### 2.2 Application of Geosynthetics

Embarking on an exploration of avant-garde solutions for soil improvement, this section immerses itself in the dynamic realm of geosynthetics, a comprehensive family comprising geotextiles, geogrids, and geomembranes. The narrative unfolds with a meticulous examination of recent research findings, casting a spotlight on the myriad applications of geosynthetics in fortifying soil index properties. As the investigation deepens, it scrutinizes the diverse methodologies employed in leveraging geosynthetics to enhance soil performance (Zargar, Choudhary, and Choudhary 2024; Carlos, Pinho-Lopes, and Lopes 2024). The analysis goes beyond a surface-level overview, delving into the intricacies of how geotextiles, geogrids, and geomembranes contribute to the geotechnical landscape. From fortifying the structural integrity of soils to countering the erosive forces that landscapes often face, this section systematically dissects the multifaceted applications of geosynthetics. The methodologies are not merely outlined but are critically evaluated for their efficacy and versatility in adapting to the dynamic challenges encountered in geotechnical engineering.

The role of geosynthetics as agents of change in soil behaviour is elucidated, offering a nuanced understanding of their pivotal contribution to resilient and sustainable geotechnical practices. Whether it is through reinforcing soil structures against external forces or providing innovative solutions for erosion control, geosynthetics emerge as indispensable tools in the geotechnician's repertoire. This section serves as a comprehensive guide, navigating through the evolving landscape of geosynthetics and illuminating their transformative influence on the intricate interplay between human infrastructure and the natural geologic environment.

#### 2.3 Bio-Mediated Soil Improvement

Embarking on a journey through the forefront of soil improvement, this section delves into the unexplored realm of bio-mediated techniques. The focus sharpens on microbial-induced calcite precipitation (MICP) and the profound impact of vegetation, pushing the boundaries of traditional soil enhancement methods. Through a meticulous and critical examination, this section unravels the inherent potential of these biological interventions to bring about positive and transformative changes to soil properties (DeJong et al. 2009; Cheng 2021).

In the context of contemporary soil engineering, where sustainability takes centre stage, bio-mediated techniques offer an environmentally friendly perspective that aligns with the principles of ecological balance. By shedding light on the underlying mechanisms and tangible outcomes of MICP and vegetation influence, this section contributes to the evolving narrative of sustainable practices in soil improvement. It not only dissects the methodologies but also explores the nuanced ways in which these biological interventions interact with and enhance the natural processes governing soil behaviour (Lim, Atmaja, and Rustiani 2020).

This section goes beyond the traditional confines of engineering approaches, emphasizing the promise and potential of bio-mediated techniques as a frontier in soil improvement. The examination of microbial-induced calcite precipitation and the role of vegetation serves as a beacon in the pursuit of environmentally conscious and sustainable solutions for shaping the geotechnical landscape(Wani and Mir 2020). Through this exploration, a deeper understanding emerges of how these bio-mediated techniques can harmonize with the natural environment, offering a pathway towards resilient and ecologically sensitive soil improvement practices.

#### 2.4 Nanotechnology in Soil Improvement

Embarking on a journey into the world of infinitesimal dimensions, this section delves deeply into the convergence of nanotechnology and soil improvement. It provides a comprehensive exploration of recent advancements in the application of nanomaterials to modify soil index properties, meticulously reviewing the benefits and challenges inherent in this cutting-edge field. The section goes beyond mere observation, shedding light on the transformative potential of nanotechnology to revolutionize the traditional paradigms of soil improvement. It dissects the intricacies of nanomaterial applications, offering a nuanced understanding of how these minute structures can bring about substantial changes in soil behaviour. From fortifying soil strength to manipulating permeability, the multifaceted impact of nanotechnology is thoroughly examined, providing valuable insights into the promising future that lies within the realm of nano-sized solutions for overcoming geotechnical challenges. By unravelling the complexities of nanotechnology's applications in soil improvement, this section contributes to the evolving discourse on innovative solutions for geotechnical engineering. The exploration not only highlights the potential of nanotechnology but also serves as a guide through the intricacies of its practical implementation. As we venture into the nano-sized landscape of soil improvement, this section offers a glimpse into the limitless possibilities that could redefine our approach to addressing geotechnical challenges on a molecular scale (Kanjana 2017; Niroumand, Balachowski, and Parviz 2023; Hatti et al. 2020).

# 3. Use of Stone Dust for Soil Modification

Sharma, Gupta, and Kumar (2014) undertook a series of experiments to investigate the effects of incorporating stone dust at designated proportions (10%, 20%, and 30%) when mixed with soil by weight. Their study revealed substantial alterations in soil properties, marking a noteworthy impact on various key parameters. Upon the addition of 30% stone powder, the angle of internal friction exhibited a substantial decrease, amounting to approximately 50%. Simultaneously, cohesion experienced a pronounced reduction, registering an impressive decline of about 64%. These findings underscore the significant influence of stone dust on the shear strength characteristics of the soil. Furthermore, the study documented noteworthy variations in the maximum dry density and optimum moisture content with the inclusion of 30% stone dust. The maximum dry density showed a decrease, indicative of changes in the soil's compaction characteristics. This reduction was complemented by a decrease in the optimum moisture content, implying alterations in the water content required for achieving maximum compaction. Intriguingly, the California Bearing Ratio (CBR) value exhibited a substantial increase throughout the experimental ranges. Specifically, the CBR value surged from an initial measurement of 5.2 to elevated levels of 16 and 18, signifying a substantial improvement in the soil's bearing capacity due to the introduction of stone dust (Figure 1). These findings highlight the potential of stone dust as a soil stabilizer, offering a cost-effective solution with positive implications for geotechnical applications, particularly in the context of road and railway construction projects.



Figure 1 Variation in CBR values with various lime concentration

Husain and Aggarwal (2015) conducted a comprehensive study on Kurukshetra soil, focusing on the impact of stone dust incorporation at various proportions (2%, 4%, 6%, 8%, and 10%) when mixed with soil by weight. The compaction results were plotted in Figure 2(a). Their investigation centred on soil subgrade stabilization, aiming to assess the efficacy of stone dust in enhancing critical geotechnical properties. The results of their study revealed a significant improvement in soil subgrade stabilization with the addition of stone dust. The California Bearing Ratio (CBR) value, a crucial indicator of soil strength, exhibited a consistent increase across the different percentages of stone dust. Specifically, the CBR value escalated from an initial measurement of 8.10 to higher levels of 12.77 and 15.32 with incremental additions of 2%, 4%, 6%, 8%, and 10% stone dust (Figure 2(b)). This upward trend in CBR values signifies an enhancement in the soil's bearing capacity and strength, indicating the effectiveness of stone dust in reinforcing the subgrade. The findings suggest that the addition of stone dust contributes positively to soil stabilization, making it a promising material for geotechnical applications, particularly in regions with Kurukshetra soil. The study not only emphasizes the potential for improving soil properties but also underscores the practicality of stone dust as a viable solution for subgrade stabilization in construction projects.

In a study conducted by Muley and Jain (2013), focused on black cotton soil and yellow soil, similar trends were observed with the addition of stone dust. The researchers noted an increase in maximum dry density and a concurrent decrease in optimum moisture content as the percentage of stone dust in the soil mix increased. Additionally, the California Bearing Ratio (CBR) values exhibited improvement, indicating enhanced soil strength and bearing capacity. Mahent and Joshi (2015) delved into the impact of increasing percentages of stone dust (ranging from 10% to 25%) when mixed with soil. Their investigation involved a murrum stone dust mixture, and the results showcased a reduction in the plasticity of the mixture, accompanied by an increase in Maximum Dry Density (MDD) values.



Figure 2 Variation in (a) OMC (%) and MDD (gm/m2) (b) CBR with various stone dust

The CBR values demonstrated a noteworthy surge from 14.37% to 28.74% with the incremental addition of 10%, 15%, 20%, 25%, and 30% stone dust (Figure 3). The findings of the study suggested that the addition of 25% stone dust by weight of murrum is particularly suitable for granular sub-base material in rural road construction projects. This conclusion underscores the potential of stone dust not only in improving soil properties but also in providing optimal conditions for the construction of robust and durable rural road infrastructures.

Abdulrasool (2015) conducted a study investigating the impact of stone dust added at specified percentages (0%, 1%, 3%, and 5%) when mixed with soil. The results revealed that stone dust played a significant role in stabilizing soil subgrade, evidenced by the improvement in California Bearing Ratio (CBR) values. As the percentage of stone dust increased, the CBR value showed a notable enhancement, rising from 4.5 to 7.1 with the addition of 0%, 1%, 3%, and 5% stone dust (refer to Figure 4(a)). This emphasizes the positive influence of stone dust on soil strength and load-bearing capacity.



Figure 3 Variation in CBR values with various added stone dust percentage

In the study conducted by Phuyal and Dahal (2021), the impact of stone dust on fine-grained soil was explored, with a focus on the Plasticity Index. Their findings indicated that an increase in stone dust percentage led to a decrease in the Plasticity Index, signifying improved soil workability. Additionally, they observed that the rise in stone dust content contributed to an increase in maximum dry density and a decrease



Figure 4 Variation in CBR values with (a) stone powder additives (%) and (b) stone dust and lime mixture (Samal and Mishra (2020)

in optimum moisture content, up to 40% stone dust. However, an interesting reversal in the results of maximum dry density and optimum moisture content was noted beyond 50% stone dust content, highlighting the nuanced effects of higher concentrations. Samal and Mishra (2020) delved into the combination of stone dust with clay soil, discovering that an increase in stone dust percentage resulted in a decrease in optimum moisture content. Notably, the maximum dry density value exhibited an increase when 40% stone dust was added to 60% clay soil. These studies collectively underscore the potential of stone dust in enhancing various soil properties, particularly in the context of rural road development. Moreover, the incorporation of lime into the stone dust mixture yielded intriguing results, with a reduction in CBR values observed at 10% stone dust but an increase in CBR values at higher percentages (20% and 30%), highlighting the complexity of soil stabilization methods.

# 4. Conclusion

In conclusion, this comprehensive review systematically navigates through a spectrum of time-honored and contemporary soil improvement methodologies, shedding light on their foundations, applications, and transformative potentials.

The exploration into the realm of industrial waste materials, including fly ash, slag, and stone dust, unveils these by-products as invaluable assets in geotechnical engineering. Through meticulous examination, this section accentuates their capacity to significantly impact crucial soil index properties such as cohesion, shear strength, and compressibility. The review synthesizes diverse studies to present a nuanced understanding of the efficacy, challenges, and limitations associated with the application of industrial waste materials, offering a valuable resource for researchers, engineers, and practitioners engaged in sustainable geotechnical practices.

Embarking on avant-garde solutions, the section on geosynthetics unravels the transformative influence of geotextiles, geogrids, and geomembranes on soil index properties. By critically evaluating their applications, this exploration provides insights into the diverse methodologies employed and underscores the versatility of geosynthetics in addressing dynamic challenges in geotechnical engineering. Geosynthetics emerge as indispensable tools, not only fortifying soil structures but also countering erosive forces, contributing to resilient and sustainable geotechnical practices.

Venturing into the unexplored territory of bio-mediated techniques, the section on microbial-induced calcite precipitation (MICP) and vegetation offers an environmentally friendly perspective. Critical examination reveals their potential to bring positive and transformative changes to soil properties, aligning with principles of ecological balance. Beyond traditional engineering approaches, this section emphasizes the promise and potential of bio-mediated techniques as a frontier in sustainable soil improvement practices.

In the minuscule dimensions of nanotechnology, the review delves deeply into the application of nanomaterials, providing a thorough exploration of their benefits and challenges. Nanotechnology emerges as a transformative force, revolutionizing traditional paradigms of soil improvement by altering soil behaviour at the molecular level. From enhancing soil strength to manipulating permeability, nanotechnology presents limitless possibilities, offering a glimpse into the future of geotechnical challenges addressed on a nano-sized scale.

Lastly, the focus on stone dust for soil modification showcases its significant potential in enhancing various soil properties, particularly in the context of rural road development. The studies presented underscore the positive influence of stone dust on soil strength, load-bearing capacity, and subgrade stabilization. The incorporation of lime further adds complexity to soil stabilization methods, highlighting the need for nuanced approaches in achieving optimal results.

In essence, this review provides a comprehensive synthesis of both traditional and cutting-edge soil improvement methods, fostering a deeper understanding of their applications and paving the way for sustainable and resilient geotechnical practices.

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# Innovative solutions for sustainable construction: A comprehensive study on environmental challenges, structural optimization, and performance evaluation of bubble deck slabs in concrete construction

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#### Abstract

Concrete, a widely employed construction material known for its sustainability, durability, and versatility, contributes significantly to global CO2 emissions. This paper explores the environmental challenges associated with concrete use, focusing on greenhouse gas emissions, sand mining, and potential health ramifications. The ready-mix concrete industry, a major concrete segment, is projected to surpass \$600 billion in revenue by 2025. Ongoing research aims to reduce emissions, transform concrete into a carbon sequestration source, and enhance the use of recycled materials for a circular economy. Concrete is expected to play a crucial role in constructing climate-resilient structures and addressing pollution by utilizing waste materials. A notable structural component, the concrete slab, has been subject to optimization efforts, with the innovative Bubble Deck system introducing plastic hollow bubbles to reduce self-weight and enhance sustainability. The system demonstrates advantages in construction efficiency, reduced material usage, and lower environmental impact.

Keywords: Concrete, sustainability, CO2 emissions, ready-mix concrete, environmental challenges, Bubble Deck system, plastic hollow bubbles, structural optimization, construction efficiency, recycled materials, circular economy, climate-resilient structures, waste utilization, greenhouse gas emissions, environmental impact.

# 1. Introduction

Concrete, renowned for its sustainability, durability, and versatility, stands as the most frequently employed construction material. It finds extensive use in erecting buildings, bridges, and pavements. Comprising cement, fine aggregate, coarse aggregate, and water, the manufacturing process of cement contributes to 5% of the world's CO2 emissions. Furthermore, due to its substantial weight, a portion of the concrete often requires removal to diminish the self-weight of the structure. Concrete, a composite material uniting fine and coarse aggregate with a fluid cement (cement paste) that solidifies over time, is the world's second most utilized substance, surpassed only by water. Its global utilization surpasses the combined usage of steel, wood, plastics, and aluminium. The ready-mix concrete industry, a major segment of the concrete market, is anticipated to surpass \$600 billion in revenue by 2025. However, this widespread use poses significant environmental challenges, primarily emanating from the substantial greenhouse gas emissions during cement production, contributing to 8% of global emissions. Other environmental concerns include illicit sand mining, effects on the surrounding environment such as increased surface runoff or the urban heat island effect, and potential public health ramifications due to toxic ingredients. Ongoing research and development focus on reducing emissions, transforming concrete into a carbon sequestration source, and enhancing the incorporation of recycled and secondary raw materials to foster a circular economy. Concrete is anticipated to play a pivotal role in constructing structures resilient to climate disasters and addressing pollution from various industries, by capturing and utilizing wastes like Plastic Waste, E-Waste, coal fly ash, or bauxite tailings and residue. As per the inherent behaviours of concrete, it exhibits strength in compression but weakness in tension.

A prevalent structural component in contemporary buildings is the concrete slab. Horizontal slabs of steel-reinforced concrete are commonly employed for constructing floors, ceilings, and exterior paving. As a fundamental part of the structure, the slab necessitates effective design and utilization. It often uses more concrete than necessary, prompting the need for optimization. The Bubble Deck slab, however, innovatively replaces a portion of the concrete with plastic hollow bubbles, created from waste plastic material, thereby reducing the self-weight of the structure. The primary impact of these plastic spheres is a 1/3 reduction in the dead load of the deck compared to a solid slab with the same thickness, without compromising its deflection behaviours and bending strength. The slab can be cast with the same capabilities as a solid one but with significantly reduced weight due to the elimination of excess concrete. Moreover, the spheres can be recycled even after the building is demolished or renovated in the future. The dead air space within the hollow spheres adds insulating value and can be filled with foam for enhanced energy efficiency, simultaneously improving fire resistance and sound insulation.

The slab stands out as a crucial structural element in building spaces, being one of the largest consumers of concrete. As the span of a building increases, so does the deflection of the slab, necessitating an increase in thickness. This results in a heavier slab, leading to larger columns and foundation sizes. These factors collectively contribute to increased material consumption, including steel and concrete [1].

Over the years, numerous efforts have been made to develop biaxial hollow slabs to reduce weight. Previous attempts involved the use of lighter materials, such as expanded polystyrene placed between the bottom and top of reinforcement, and various types like waffle slabs or grid slabs. However, only waffle slabs have found limited use in the market due to issues related to reduced shear resistance, local punching, and fire concerns [2].

In the 1990s, a revolutionary system, known as the Bubble-Deck system, was introduced by Jorgen Breuing to address these challenges. This system employs recycled plastic balls to create air voids while maintaining strength through arch action. These bubbles contribute to a significant reduction in dead weight by approximately 30% while simultaneously increasing capacity by up to 100% with the same thickness [3].

The Bubble-Deck system offers a multitude of advantages in both building design and construction. It boasts several green attributes, including a decrease in total construction materials, the utilization of recycled materials, reduced energy consumption, lower CO2 emissions, and a diminished need for transportation and crane lifts. This makes the Bubble-Deck system more environmentally friendly compared to other concrete construction techniques [4].

#### 2. Literature Review

Sergiu Călin, Roxana Gînțu, and Gabriela Dascălu's study in 2009 provides a summary of tests and studies conducted abroad on the Bubble Deck slab system. The research encompasses bending strength, deflection behaviour, shear strength, punching shear, dynamic punching shear, anchoring, fire resistance, sound insulation, and various other tests. The Bubble Deck is noted to behave like a spatial structure, exhibiting higher shear strength than conventional slab systems.

In 2002, Martina Schnellenbach-Held and Karsten Pfeffer investigated the punching behaviours of biaxial hollow slabs, emphasizing the Bubble Deck's application as a flat slab. The study explores the influence of cavities on punching behaviour through tests at the Institute for Concrete Structures in Darmstadt and nonlinear computations using the Finite Element Method.

A 2009 paper by Sergiu Călin, Ciprian Asăvoaie, and N. Florea presents experimental programs related to concrete slabs with spherical gaps, focusing on bubble deck slabs in conditions similar to real construction. The study involves the creation of a 1:1 scale slab element subjected to static gravitational loadings to determine deflection, cracking, and failure characteristics. Reshma Mathew and Binu. P's 2016 study investigates the punching shear strength development of Bubble Deck slabs using GFRP stirrups. Due to the reduced weight of bubble deck slabs, punching shear capacity is a significant concern. The study employs a GFRP strengthening system, noting increased load-carrying capacity of up to 20% in strengthened bubble deck slabs compared to their un-strengthened counterparts. The strengthened bubble deck also exhibits lower deflection.

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A. Hammoud, F. Dehn, and H. G. Matthies, (2015). "Experimental Investigation of Lightweight Concrete Slabs with Spherical Voids for Bridge Applications." This study presents experimental findings on the performance of lightweight concrete slabs with spherical voids, particularly in the context of bridge applications.

N. Sivakumar and R. Vasudevan, (2013). "Behavior of Bubble Deck Slabs under Flexural Loading." The paper investigates the behavior of Bubble Deck slabs under flexural loading conditions, examining factors such as load-carrying capacity, deflection, and structural efficiency.

J. M. Mansour, K. Sobhana, and M. E. Al-Ashwal, (2011). "Structural Performance of Bubble Deck Slabs in Fire." This study assesses the structural performance of Bubble Deck slabs under fire conditions, considering aspects such as fire resistance, thermal behaviour, and the influence of spherical voids on slab performance.

X. Yu, X. Yan, and Y. Bai, (2020). "Seismic Performance of Bridge Decks with Spherical Voids." The research investigates the seismic performance of bridge decks incorporating spherical voids, examining the impact on structural integrity and seismic resistance.

A. M. D. Giamundo, E. M. Marino, and M. di Ludovico, (2014). "Analysis and Design of Slabs with Hollow Spherical Inclusions." This paper delves into the analysis and design considerations for slabs incorporating hollow spherical inclusions, exploring structural behaviour and load distribution.

Julian W. Bull, "Bubble Deck - A New Approach to Flat Slab Construction," The Structural Engineer, Volume 82, Issue 2, "2004". This paper discusses the Bubble Deck technology as a novel approach to flat slab construction. It explores the advantages of using spherical hollow balls to reduce the weight of slabs, improving efficiency and sustainability in construction.

Mona I. El-Hawary's study delves into the structural behavior of Bubble Deck slabs under flexural loading. The research investigates how the introduction of spherical hollow balls affects the performance of slabs in terms of bending and load-carrying capacity.

M. Czaderski, "Sustainable Structural Engineering: Implementing Bubble Deck Slabs in Practice." This paper explores the practical implementation of Bubble Deck slabs in sustainable structural engineering. It discusses the environmental benefits and challenges of incorporating spherical hollow balls into slabs, emphasizing real-world applications.

Felicetti et al.'s study investigate the experimental behaviour of Bubble Deck slabs using recycled aggregate concrete. The focus is on sustainability by combining the innovative use of spherical hollow balls with eco-friendly concrete materials.

Dogangun (2019). This paper explores the structural performance of Bubble Deck slabs under dynamic loading conditions. It evaluates how the introduction of spherical hollow balls influences the response of slabs to dynamic forces, providing insights into potential applications in seismic-prone regions.

Haron and Aziz (2008) provide an overview of the fire resistance of Bubble Deck slabs. The paper examines how the inclusion of spherical hollow balls affects the slabs' behaviour in fire conditions, addressing a critical aspect of structural safety.

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Aghayari,R.,Hosseini,M.,&Ramezanianpour, A. A., (2019). Study explores the use of various types of fibers as reinforcement in Bubble Deck slabs. It examines how fiber reinforcement influences the structural properties, durability, and crack resistance of the slabs.

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Ozyurt, I., Erdem, E., & Uz, V. E., (2014). This research focuses on the acoustic properties of buildings utilizing Bubble Deck slabs. It evaluates the sound insulation and transmission characteristics, offering insights into the potential advantages of noise control.

Kim, J. H., & Park, J. H., (2016). The study explores the dynamic behaviour of Bubble Deck slabs under vibration loads, providing insights into their response to dynamic forces and potential applications in structures susceptible to vibrations.

Yu, J., Zhang, Z., & Zhang, Z., (2020). This study focuses on the fire resistance of Bubble Deck slabs, conducting numerical simulations to assess their performance under different fire scenarios. The research contributes insights into the structural behaviour of these slabs in fire conditions.

Morsy, A. M., & Selim, R. S., (2017). Investigating the durability aspects, this study explores how Bubble Deck slabs perform when exposed to harsh environmental conditions. It assesses factors such as moisture, temperature variations, and chemical exposure, providing insights into the long-term resilience of the slabs.

Nguyen, T., & Tao, P., (2015). Conducting a life-cycle assessment, this research compares the environmental impact of Bubble Deck slabs with traditional slabs. The study considers factors such as raw material extraction, production, transportation, and end-of-life disposal to evaluate the overall sustainability.

Huang, S., Li, Q., & Wang, C., (2019). Focusing on economic aspects, this study compares the cost-effectiveness of Bubble Deck slabs with conventional slabs in building construction. It analyses factors such as material costs, construction time, and overall project expenses.

Li, H., Wu, C., & Yang, Y., (2018). This research explores innovative applications of Bubble Deck technology beyond traditional building construction. It discusses its potential in various infrastructure projects, such as roadways, pedestrian bridges, and industrial structures.

Jin, X., Chen, Z., & Zhang, W., (2016). Investigating the long-term behavior of Bubble Deck slabs, this study focuses on shrinkage and creep. It provides insights into how these slabs perform over time in terms of deformation and stability.

# 3. Case Study: Bubble Deck Slab

The Bubble Deck slab's geometry is characterized by the strategic placement of spheres of a specific size, arranged in a modular grid to achieve a desired overall deck thickness, contingent upon the diameter of the balls utilized. The innovative Bubble Deck technology offers notable advantages, facilitating a 20% faster floor construction process, and minimizing formwork and beam requirements, thereby resulting in a 10% reduction in construction costs. Moreover, it aligns with sustainability goals by contributing to a 35% reduction in concrete usage.

The primary objective is to assess the practicality of employing hollow spherical plastic balls within a reinforced concrete slab, known as the Bubble Deck slab. This involves an in-depth examination of the structural, economic, and environmental implications of integrating such elements.

#### 3.1 Comparison Procedure

Develop a systematic procedure for a comprehensive comparison between a conventional solid slab and the innovative Bubble Deck slab. This comparison encompasses various parameters, including structural performance, construction efficiency, and cost considerations.

## 3.2 Bending (Deflection) Behaviour Study

Investigate and analyze the bending behaviour, specifically deflection characteristics, of both conventional and Bubble Deck slabs. This study aims to provide insights into how the introduction of hollow spherical plastic balls influences the flexural properties of the slabs.

## 3.3 Behavioural Study

Conduct an extensive study on the overall behaviour of conventional slabs and Bubble Deck slabs. This involves examining factors such as load-bearing capacity, durability, and response to external forces, shedding light on the comparative structural performance of the two types of slabs.

# 3.4 Effects of Hollow Plastic Ball Usage

Focus on understanding the effects of incorporating Hollow High-Density Polyethylene (HDPE) balls into reinforced concrete slabs. Explore how the use of these hollow plastic balls influences various aspects of slab behaviour, including strength, weight, and environmental impact. This case study aims to provide a holistic exploration of the Bubble Deck technology, offering a comprehensive understanding of its practicality, performance compared to traditional slabs, and the specific effects associated with the utilization of hollow plastic balls in the construction of reinforced concrete slabs.

# 4. Materials Required

In the construction of a Bubble Deck slab, various materials are employed to ensure structural integrity and optimal performance.

The key materials include Hollow Balls / Bubbles: The hollow balls utilized in Bubble Deck slabs are crafted from high-density polypropylene plastic, a nonporous material known for its non-reactive nature with both concrete and reinforcement bars. These hollow bubbles exhibit sufficient strength and stiffness to effectively bear applied loads. The diameter of the bubbles typically ranges from 200mm to 400mm, determining the slab depth within the range of 200mm to 450mm. It is essential that the spacing between bubbles exceeds 1/9th of the bubble diameter. The hollow balls can assume either a spherical or ellipsoidal shape to accommodate structural requirements.

Concrete: The concrete selected for joint filling in the Bubble Deck floor system must meet or exceed class 20/25. Self-compacting concrete is often the preferred choice due to its ability to flow easily within the voids created by the hollow balls, ensuring efficient filling and overall structural stability.

Reinforcement Bars: The reinforcement of Bubble Deck slabs consists of two meshes, positioned at the bottom and upper parts of the slab, and can be secured through tying or welding. The steel reinforcement is configured in two distinct forms—meshed layers and diagonal girders designed to provide vertical support to the hollow bubbles. The spacing between these reinforcement bars is specifically tailored to correspond with the diameter of the chosen hollow bubbles, and the quantity is determined by the transverse ribs of the slab. This strategic placement of reinforcement ensures the structural integrity and load-bearing capacity of the Bubble Deck slab.

Preparation of Reinforcement Mesh: In the construction of Bubble Deck slabs, a distinctive approach is employed for the preparation of the reinforcement mesh. Steel bars are strategically incorporated to cater to the tension zone of the slab, ensuring optimal tensile strength where it is most needed. Simultaneously, concrete is introduced to address the compression zone, capitalizing on its ability to withstand compressive forces. This methodical arrangement of steel bars and concrete is a key feature of the Bubble Deck system, strategically leveraging the inherent strengths of each material to enhance the overall structural performance of the slab.

# 4.1 Interaction Between Bubbles and Reinforcement

The prospect of direct contact remains largely theoretical, as the spherical voids do not seamlessly slot between the reinforcement bars. During assembly and the subsequent compaction of on-site concrete, the balls undergo slight movements, leading to the encapsulation of some grout around them. Even in the unlikely scenario of contact between the plastic balls and the steel reinforcement, the internal environment within the void remains inherently dry and shielded. Notably, there is no breach, apart from microscopic cracking, that connects the internal concrete environment to the external air.

This situation presents a superior condition compared to the inclusion of plastic rebar spacers within solid slabs, which introduces a discontinuity within the concrete. In solid slabs, this discontinuity creates a pathway between the external air and the reinforcement bars, a circumstance avoided by the enclosed and protected voids in the Bubble Deck system.

#### 4.2 Comparison with Conventional Slabs

In a meticulous experimental exploration, diverse slabs were crafted to draw numerical comparisons:

Conventional Slab: M30 grade concrete was employed, aligning with the stipulations of IS Code 456-2000 and IS 10262:2009.

Bubble Deck (Continuous Arrangement): Embracing a continuous bubble arrangement, this slab's design adhered to the German codes DIN 1045 (1988) or DIN 1045 (2001).

Alternative Bubble Deck Slab (Type I): A distinctive alternative bubble deck slab was meticulously crafted, introducing a varied bubble configuration by German codes.

Alternative Bubble Deck Slab (Type II): A nuanced variation, Type II of the alternative bubble deck slab featured an altered bubble arrangement, offering a unique perspective.

#### 4.3 Details of Slab Casting

Both conventional and Bubble Deck slabs materialized through the casting process, featuring the innovative use of hollow high-density polyethylene (HDPE) balls.

Conventional Slab: Embracing M30 grade concrete, this slab's dimensions unfolded at 1 m x 1 m x 0.125 m. Reinforcement showcased a strategic assembly with 4 crank bars longitudinally, 4 crank bar laterals, and 4 distribution bars, each meticulously placed. Reinforcement bars, with a diameter of 8mm spaced at 240mm intervals, were orchestrated to a total length of 960mm, featuring a 45-degree bend at 150 mm. Continuous Bubble Deck Slab: Distinguished by its seamless bubble arrangement, this slab presented an innovative take on structural design. Alternative Bubble Deck Slab (Type I & II): The reinforcement strategy mirrored the continuous arrangement, ensuring consistency. The alternative bubble deck slab ventured into experimentation, altering bubble volumes to gauge its consequential impact on structural strength.

Type II of the alternative bubble deck slab introduced a distinctive bubble configuration, setting it apart from its Type I counterpart.

# 5. Result and Discussion:

The various tests on materials like cement and aggregates are tabulated as shown in Tables 1-3.

SL.NO	Properties	Test results	IS:4013- 1963
1.	Standard consistency	33%	24%-34%
2.	Initial setting time	45 MIN	Minimum of 30min
3.	Specific gravity	3.128	3-4
4.	Fineness	2.05 %	10%

Table 1: Test of cement

 Table 2: Test of Coarse Aggregate

SL. No	Properties	Test Results	I.S Recommendation
1	Nominal Size Used	Less than 20mm	
2	Specific Gravity	2.57	IS2386-1963
3	Moisture Content	0.157%	IS2386-1963
4	Water Absorption	0.45%	IS2386-1963
5	Crushing Strength	30.05%	IS2386-1963
6	Shape Test		
	Flakiness index	14.95%	IS2386-1963
	Elongation index	26%	IS2386-1963

Sl. No	Mix Proportion	No Days		Compressive Strength N/Mm <sup>2</sup>		ressive ngth	
					7 days	14days	28days
1	Conventional concrete	7	14	28	13.28	22.05	31.24
2	Conventional concrete + one plastic ball reduction of concrete	7	14	28	11.87	12.05	9.45
3	Conventional concrete + two plastic ball reduction of concrete	7	14	28	4.52	11.524	11.23

 Table 3: Compressive Strength

# 6. Conclusion

With one plastic ball, the compressive strength initially increases for 7 days but experiences a sudden decrease after 28 days. When using two plastic balls, the initial strength is significantly lower. While the compressive strength characteristics of conventional concrete are suitable for construction, concrete containing plastic balls is not recommended due to a notable decrease in compressive strength compared to conventional concrete. The 7-day initial strength of concrete with plastic balls is 13% higher than that of conventional concrete, but by the end of 28 days, its compressive strength diminishes by nearly 20% compared to conventional concrete.

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# 10. Optimizing furrow irrigation for sustainable agriculture in a changing world

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## Abstract

In light of the profound challenges posed by climate change and the ever-expanding global population, the imperative to refine agricultural practices has never been more pressing. This study embarks on a journey to assess the efficiency of furrow irrigation, a pivotal technique in agriculture, with a particular emphasis on its effects on soil moisture content and plant growth. As we grapple with climate change and the increasing demand for food production, the optimization of irrigation methods takes on paramount significance. The present study delves into furrow irrigation, a widely adopted practice, scrutinizing its influence on the growth of crops and its impact on water consumption. Through meticulous experimentation within a controlled setup, we replicate real-world conditions, utilizing gap-graded soil to replicate natural soil diversity. Our findings elucidate the critical role of comprehending soil properties and implementing efficient water management strategies in ensuring the triumph of furrow irrigation within the realm of agriculture. In a world where water resources are finite and agricultural demands continue to surge, the insights gleaned from this study offer valuable guidance for enhancing the sustainability and productivity of modern farming practices.

Keywords: Furrow irrigation, soil moisture content, water management, irrigation efficiency, agricultural practices.

# 1. Introduction

The intersection of a changing global climate and a steadily growing human population is imposing profound challenges on agriculture, foremost among them being the recurrent droughts that exacerbate the already limited water resources (Chai et al. 2016; Imtiaz et al. 2009). Projections by the Food and Agriculture Organization (FAO) indicate that developing nations will require an additional 15% of water for agricultural purposes by 2030. This looming water scarcity threat has prompted a renewed emphasis on household-level irrigation development as a means to enhance food security (Makombe, Kelemework, and Aredo 2007; Singh, Kundu, and Bandyopadhyay 2010). Mitigating these challenges necessitates prioritizing food security through the implementation of advanced agricultural techniques aimed at boosting crop productivity and adapting to shifting climatic and environmental conditions. The erratic and unpredictable rainfall patterns in regions like West Bengal pose a particularly significant challenge for predominantly Kharif crops, resulting in severe soil moisture stress at the root level and a compelling need for substantial irrigation (VEERANNA and Mishra 2017).

Studying and optimizing crop water requirements at different growth stages become paramount for efficient irrigation practices, given the pivotal role irrigation plays in modern agriculture. To facilitate this endeavor, computer models like CROPWAT 8.0 have been developed to assess crop water requirements and enhance the precision of irrigation scheduling (Ratna Raju et al. 2016). These models take into account various factors such as effective rainfall, climatic data, meteorological conditions, and soil moisture levels (Reddy 2012). Furthermore, CROPWAT 8.0 simulates reference crop evapotranspiration and incorporates soil characteristics, providing valuable insights into cropping patterns under varying rainfed and non-rainfed conditions (Babu et al. 2014; Ewaid, Abed, and Al-Ansari 2019).

Efficient water management practices hold the potential to significantly elevate the annual income of irrigation users, potentially up to eight times higher than those who rely solely on rainfed agriculture (Berhe et al. 2022). However, it's essential to acknowledge that small-scale irrigation schemes often operate sub optimally (Abera et al. 2019; Habtu et al. 2020). Additionally, the widespread practice of applying excessive water through uncontrolled flooding irrigation, often without considering specific crop requirements or the limitations of water availability, has led to low production levels and suboptimal economic returns (Beyene et al. 2018). Such improper irrigation management can result in a substantial reduction in crop yields, potentially up to 60% when compared to the full crop evapotranspiration (ETc) requirements (Doro 2012). Flooding irrigation, known for poor water uniformity, challenges in water control, and high evaporation rates, has proven to be inefficient in terms of water use (Wang et al. 2020). Consequently, there is an urgent need to enhance water use efficiency by adopting appropriate water management strategies, including deficit irrigation techniques, timed irrigation to coincide with critical crop growth stages, and the implementation of more efficient irrigation practices.

For achieving enhanced crop growth and realizing higher yields, it is imperative to incorporate optimized soil-water-plant-atmosphere relationships within effective root zone systems (Fanish, 2013). This holistic approach is essential for maximizing agricultural productivity while minimizing water wastage, a crucial step towards addressing the pressing challenges faced by agriculture in an ever-changing world.

In the realm of agricultural practices and water resource management, the efficacy of irrigation systems holds paramount importance. In this context, the present study embarks on a mission to delve into the intricate relationship between furrow irrigation systems and the fundamental aspects of plant growth and water consumption. With a pressing need to optimize water usage in agriculture, it becomes increasingly crucial to explore and comprehend the impact of irrigation methods on the growth of plants and their overall water requirements. In particular, the study focuses its lens on furrow irrigation, a widely employed technique in the agricultural landscape. Furrow irrigation, known for its ability to deliver water directly to the root zone of plants, holds the potential to significantly influence crop development and, in turn, agricultural productivity. The study seeks to unravel the nuances of this irrigation system, shedding light on its effectiveness in meeting the water needs of plants while nurturing their growth.

As global challenges such as changing climate patterns and burgeoning population continue to reshape the agricultural landscape, our pursuit of sustainable and efficient irrigation practices takes on ever-increasing significance. In this backdrop, this study endeavours to contribute valuable insights into the pivotal role of furrow irrigation systems, offering a deeper understanding of their impact on plant growth and water consumption. Through meticulous analysis and observation, the study aims to provide a foundation for informed decisions in agriculture, aligning our practices with the evolving demands of a dynamic world.

#### 2. Methodology

To thoroughly assess the efficiency and effectiveness of furrow irrigation systems, a meticulously designed prototype was created and positioned within a mobile field setup measuring 8x8 meters. Each individual irrigation system was carefully enclosed by robust 15-inch brick walls, ensuring a distinct and isolated testing environment. The choice of location was critical, and the setup was strategically placed on a solid concrete surface floor to prevent any potential issues related to seepage or unintended drainage that could compromise the precision of the experimentation.

The pivotal component of this study was the selection of the soil sample, which was diligently collected through a distributed sampling approach. The chosen soil, a reddish-brown sandy clay, was extracted from depths ranging from 1.0 to 2.0 meters within a borrow pit situated within the confines of the Malandihi College campus in Durgapur. This particular soil type falls within the category of ferruginous tropical soils, with its origin traced back to igneous and metamorphic rocks, making it an intriguing subject of study due to its relevance in agricultural and geotechnical contexts.

In terms of the experimental setup, Aloe vera plants (Aloe) were selected as the vegetation of choice to simulate real-world agricultural conditions. Within the setup, the soil ridge was thoughtfully elevated to a height of 5 inches above the solid concrete surface, while the furrow itself was positioned at a higher elevation, 15 inches above the ground level. Precision was paramount in controlling water distribution, and to this end, a water tank valve was meticulously connected to the mainline, with manual adjustments available for regulating the pressure head that governed the water flow rate.

For furrow irrigation, a hands-on approach was adopted, with water sources manually supplied from a designated corner of the setup, ensuring a consistent and uniform distribution of water across all furrows. The prototypes themselves were expertly crafted in a workshop environment to facilitate controlled simulation of rainfall events, accurately timed within specific durations to mimic real-world conditions.

The experimental phase of this study extended over a duration of 60 days, during which meticulous observations and data collection took place. Furrow irrigation was administered once per week, with each irrigation event lasting for a well-considered period of 30 to 40 minutes. This comprehensive and meticulously executed study aimed to provide valuable insights into the efficiency and performance of furrow irrigation systems under controlled conditions, offering critical information for their practical applications in agriculture, water resource management, and beyond.

#### 3. Result and Discussion

The particle size distribution, as depicted in Figure 1, offers a captivating glimpse into the nature of the soil under scrutiny. It unveils a distinctive attribute, categorizing the soil as gap-graded, a term that signifies a heterogeneous

mix of particle sizes spanning from 0.075 mm to 4.75 mm.



Figure 1 Particle Size distribution for the soil used in the study

However, within this wide spectrum of sizes, there is a conspicuous absence or marked reduction in specific size fractions, most notably within the ranges of 1 mm to 2.46 mm and 0.425 mm to 0.6 mm. Gap-graded soils, by nature, tend to showcase an abundance of coarser particles, including gravel and larger sand constituents. These robust coarse elements significantly bolster the soil's drainage properties, rendering it particularly advantageous in various engineering applications.

What truly sets gap-graded soils apart is their striking deficiency in fine fractions, such as silt and fine sand, resulting in a non-uniform distribution of particle sizes within the soil matrix. This distinct granular structure is a direct consequence of the predominance of coarse particles. This unique soil composition grants gap-graded soils their relevance in specialized engineering scenarios where specific characteristics like permeability and compaction are of paramount importance. Understanding and harnessing these properties are crucial for tailored applications in construction, geotechnical engineering, and civil infrastructure development.

A deeper examination of the moisture content, as depicted in Figure 2, unravels an essential aspect, particularly when considering furrow irrigation. This irrigation method, which inundates the entire area with water, inherently gives rise to an accelerated rate of evaporation, a phenomenon that becomes more pronounced during the scorching summer months. In response to these heightened evaporation rates, a strategic and proactive approach to water supply becomes imperative. Failure to meet these water demands can lead to the untimely desiccation of furrow channels, effectively impeding the critical flow of water to the furthest reaches of the furrow irrigation system. Such an impediment, in turn, poses a substantial risk to the vitality of cultivated plants, potentially resulting in their demise.



Figure 2 Average moisture content of the Soil used in the present study

The extensive coverage of the furrow irrigation system by water throughout the channels exacerbates the challenge posed by high evaporation rates. This challenge is distinctly reflected in the growth trends illustrated in Figure 3. Notably, it becomes evident that plants achieve their zenith in growth within the initial 5 weeks following transplantation. These findings underscore the profound importance of comprehending the intricate interplay between soil characteristics, effective water management practices, and seasonal variations. This holistic understanding is pivotal, especially when dealing with gap-graded soils, as it serves as the cornerstone for optimizing the performance of furrow irrigation systems and ensuring the flourishing of cultivated vegetation. These insights carry substantial implications for agriculture, engineering, and environmental management, providing a valuable foundation for future research and practical applications.

The soil was observed to be a Gap-graded characterized by a wide range of particle sizes (0.075 mm-4.75 mm), yet certain size fractions are conspicuously absent or significantly reduced (1 mm-2.46 mm and 0.425 mm- 0.6 mm). Typically, gap-graded soils exhibit a prevalence of coarse particles, including gravel and larger sand components, contributing to their effective drainage capabilities. What sets gap-graded soils apart is the notable dearth of

fine fractions such as silt and fine sand, resulting in an uneven distribution of particle sizes. The granular structure of gap-graded soils, stemming from the dominance of coarse particles, makes them suitable for specific engineering applications where desired properties like permeability and compaction are pivotal.

The moisture content of the at different instances is presented in Figure 2. In case of furrow irrigation, since the entire area is covered with water, the rate of evaporation is particularly high which may result into fast reduction in moisture content of the soil. In summer, the evaporation rates become higher and we needed to supplies more water otherwise the furrow channel will get dry and the sufficient amount water won't reach to the end of the channels in furrow irrigation system and that causes dead of the plants.

Due to a very large area was covered by water flow throughout the channel of furrow irrigation system the rate of evaporation is high. The growth achieved during the period for the specific plant is presented in Figure 3. As it can be observed that the plants archived optimum growth during the first 5 weeks after plantation.



Figure 3 Average plant height at different time period observed in the present study

#### 4. Conclusions

In summary, the soil in this study was identified as gap-graded, characterized by a wide range of particle sizes with certain size fractions notably absent. Gap-graded soils are rich in coarse particles like gravel and larger sand, but lack fine fractions like silt and fine sand, leading to uneven particle distribution. This type of soil is well-suited for specific engineering applications due to its granular structure. Moisture content was closely monitored during the experiment, revealing high evaporation rates in the furrow irrigation system, especially during summer. This required frequent water supply to prevent drying of furrow channels and ensure sufficient water reached the plants. Optimal plant growth was observed within the first 5 weeks after planting. These findings highlight the importance of understanding soil properties and effective water management for successful furrow irrigation in agriculture.

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# 11. Optimizing the use of reclaimed paving materials in granular sub base for road construction: An extensive analysis

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## Abstract

Reclaimed Paving Materials offer a promising solution for road construction due to their availability and potential for cost savings. By reusing RPM materials, we can reduce the consumption of fresh aggregates, conserve natural resources, and minimize waste generation. However, the effective utilization of RPM in the granular sub-base requires optimization techniques and careful consideration of various factors. This study aims to optimize the use of Reclaimed Paving Materials in granular sub-base, providing an open alternative for Indian roads. This approach helps reduce construction costs and ensures the sustainability of raw materials. Road construction is a costly process, involving millions of tons of aggregate. Given the scarcity of fresh aggregate, the present study explores the possibility of using recycled aggregate as a replacement for a portion of the fresh aggregate. This aligns with the government's goal of conserving budgets and promoting environmentally friendly practices through "Green Technology." Therefore, recycling pavements emerges as an efficient solution for road construction and maintenance, offering significant advantages such as cost savings, environmental preservation, and the preservation of virgin materials.

Keywords: Reclaimed Paving Materials (RPM), Granular Sub Base (GSB), Ministry of Road Transport and Highway

# 1. Introduction

Reclaimed Paving Materials (RPM) refer to materials obtained from existing asphalt pavements that have been removed or milled. Nowadays abundant waste is available due to resurfacing and upgradation of the existing roads like major district roads, state highways, and national highways. these materials are then recycled and reused in new asphalt mixtures. RPM can include a combination of aged bituminous (asphalt binder), aggregates, and other pavement materials. Recycling RPM helps to reduce the demand for new raw materials and minimizes the amount of waste generated from pavement removal processes. Since the quantities available are more highway and transportation engineers to find solutions to reuse the reclaimed paving materials thereby consuming the waste and conserving the natural resources. It is obtained either by milling or by a full-depth recovery method. It may be a highly useful material when crushed and screened properly.

The utilization of RPM aggregate remains relatively uncommon in India and other developing nations. Apart from financial investments, the availability of raw materials is a critical factor in road development projects. The Indian Roads Congress, envisioning future road advancements in the country, has indicated a need for 3500 million cubic meters of aggregates in its special publication, "Road Development Plan VISION: 2021." As India's road network undergoes modernization and the travel demand continues to rise, these investments will inevitably escalate. Consequently, India faces a pressing requirement to adopt a sophisticated approach for road construction and maintenance, to minimize expenses and decrease reliance on raw materials.

To achieve this, the integration of recycled aggregate as a substitute material can reduce the demand for fresh aggregate. In the current study, the RPM aggregate originates from the remains of dismantled roads. By analyzing existing literature and case studies, the research aims to pinpoint the most effective practices and guidelines for maximizing RPM utilization in the granular sub-base of rural roads. The findings will contribute to the development of sustainable and cost-effective solutions for road construction, benefiting rural communities, minimizing construction costs, and promoting environmental stewardship.

# 2. Literature Review

The primary objective of this review is to conduct a thorough examination of current practices and identify effective strategies for maximizing the utilization of Reclaimed Paving Materials (RPM) in the granular sub-base of village roads. The study will extensively analyze various methodologies and techniques used in previous research and projects to gain valuable insights into the performance, durability, and structural integrity of RPM-based granular subbase layers that have earned the reputation of being the most recycled material worldwide, finding applications as an aggregate substitute in bituminous mixtures, granular sub-bases, base aggregates, and embankment or fill materials. The material under review for this research is sourced from diverse resources. Some of these resources are directly relevant to the present study, while others are only loosely related but still contribute valuable insights to the topic. The review aims to amalgamate and synthesize this information to provide a comprehensive understanding of the optimization strategies for incorporating Reclaimed Paving Materials in the granular sub-base of road construction. By exploring and evaluating the performance of RPM in previous projects and studies, this review will serve as a valuable resource for engineers, researchers, and policymakers engaged in rural road development projects. The findings will contribute towards developing sustainable road construction and maintenance practices, aiming to minimize costs, reduce dependency on

raw materials, and enhance the overall quality and longevity of village roads. Ultimately, this review aims to play a crucial role in advancing the state of knowledge in this field, encouraging the widespread adoption of RPM in granular sub-base applications, and fostering more environmentally friendly and economically viable road development practices in India.

#### 2.1 History at a Glance

The recycling of bituminous pavements has emerged as an advanced methodology adopted in several countries for the rehabilitation and restoration of pavements. Although the concept was initially introduced in 1915, it gained popularity during the 1970s when there was a significant surge in the price of bituminous materials. The ensuing inflationary pressures compelled the exploration and implementation of recycling techniques as a means to mitigate construction costs and promote sustainability within the industry.

Since then, extensive research and development efforts have been dedicated to studying and refining the recycling process. The performance of these high Reclaimed Paving Materials (RPM) mixtures has been thoroughly examined, and it has been observed that they exhibit comparable performance characteristics to conventional mixes. This finding has provided further impetus for the widespread adoption of recycling practices in pavement construction and maintenance.

#### 2.2 Present Scenario

The utilization of Reclaimed Paving Materials (RPM) is an emerging technique in India, holding promising benefits for both the government and contractors in terms of efficiency and cost savings. Although research on RPM in India is still limited, it is extensively employed in the United States and various other countries, offering valuable insights into best practices. To improve mix design and ensure quality control, ongoing advancements are being made in RPM sampling, testing, and material characterization. These efforts are targeted at supporting contractors and transportation departments in optimizing the utilization of RPM in road construction. Assessments based on regional requirements cover a range of factors, including low-temperature testing, rutting susceptibility, cracking resistance, moisture susceptibility, and mixture stiffness. Evaluating these parameters is critical to guaranteeing the pavement's performance and long-term durability. By continuously refining these techniques and assessments, the industry aims to enhance the effectiveness of RPM integration, leading to more resilient and long-lasting pavements. The bituminous industry continues to strive for an enhanced understanding of the correlation between performance tests and real-world field performance. Ongoing efforts focus on identifying the most effective performance tests that can accurately predict the behavior of RPM mixes under different conditions. This research helps pave the way for informed decision-making and improved quality assurance in RPM utilization.

#### 2.3 Studies on Recycling

Terrel R.L. and Fritchen D.R. (1978) [1] researched "Performance of recycled asphalt concrete". The performance of the recycled mixes was evaluated by comparing them with the control mixes using resilient modulus testing. Resilient modulus measures the ability of the pavement material to recover its shape after being subjected to deformation from traffic loads. To assess the resilient modulus, an accelerated aging procedure was employed, which involved subjecting the mixes to alternating freezing and thawing cycles. This accelerated aging process aimed to simulate the harshest moisture conditions that the pavement might experience in its lifetime. By conducting these tests, researchers could determine how well the recycled mixes would withstand the effects of repeated freeze-thaw cycles and assess their overall performance in comparison to the control mixes.

Mc- bee et al. (1988) [2], conducted a "Detailed evaluation study on the recycled mixes" The study was a combination of field and laboratory evaluation and suggested that the use of a rejuvenator in recycled bitumen mix would decrease the potential rutting and also increase the life of the recycled pavement.

Kandhal P.S. et al. (1995) [3] performed "A laboratory study of recovered binder and a detailed evaluation on the recycled mixes in Georgia". The controlled experiments involved analysing the blending process of Reclaimed Paving Materials (RPM) with a fresh mixture. Various percentages of screened RPM were mixed with new coarse aggregate. One mixture, which consisted of 20% screened RPM, underwent staged extraction and recovery. The findings from this study revealed that only a minor portion of the aged bituminous in RPM actively took part in the remixing process.

Mansour Solimanian Thomas.W.Kennedy, Weng. O. Tam, (2006)[4] - "Effect of Reclaimed Paving Materials on binder properties using the SUPERPAVE system" The main aim of this study was to establish guidelines for integrating Reclaimed Paving Materials (RPM) into bituminous mixes, following the SUPERPAVE binder specifications. The study's findings revealed that with an increase in the percentage of RPM binder, the stiffness of the binder also increased. This stiffness change occurred at a consistent rate throughout the entire range of 0-100% RPM binder, or it escalated at lower temperatures. Moreover, the rate of stiffness changes either remained constant across the 0-100% RPM range or increased when higher percentages of RPM were added to the blend. These results provide valuable insights into the behaviour and characteristics of RPM-based bituminous mixes, guiding engineers in optimizing their usage and ensuring proper pavement performance.

West R. et al. (2009) [5]-The study's conclusions indicated that the recycled pavement sections performed well on the test track, even under heavy loading conditions. The positive results suggest that the use of recycled materials in pavement construction can be a viable and effective option, meeting performance requirements and demonstrating their suitability for actual road applications. The data gathered from both the field and laboratory evaluations provided valuable insights into the durability and performance of recycled pavements, contributing to the ongoing efforts to implement sustainable and cost-effective road construction practices. Valdes G. et al. (2010) [6] carried out "A study on recycled asphalt mixes containing higher RPM percentages". The objective of the research was to rehabilitate a specific section of the highway. To achieve this, two semidense mixtures were created, consisting of maximum aggregate sizes of 12 mm and 20 mm. These mixtures contained 40% and 60% of Recycled Pavement Material (RPM) respectively. The properties of these mixtures were then compared to control mixtures that utilized two grades of bitumen, namely penetration grade 60/70. Ultimately, the conclusions drawn from the study were as follows: The impact test results for the laboratory-prepared recycled mixes were satisfactory and comparable to those of the virgin mixes. It was found that an RPM content of 60% could be effectively incorporated into the recycled mixes, provided that proper handling and mix design practices were employed. Furthermore, the analysis of stiffness modulus and indirect tensile strength tests indicated that the performance of the recycled mixes was comparable to that of the virgin mixes. Eric J. McGarrah-(2010) [7] "Evaluation of current practices of Reclaimed asphalt pavement/virgin aggregate as base course material" This report evaluates previous studies that have investigated the characteristics and behaviours of both 90% RPM mixtures and blends of RPM with virgin aggregates. Several notable findings from this analysis are presented. While a maximum percentage of 50% RPM is commonly used, it does not necessarily indicate the optimal percentage, and it is recommended to restrict it to 27%. RPM is known for its inherent variability, and by ensuring a consistent gradation in the produced RPM, the extent of this variability can be minimized, resulting in more reliable performance outcomes.

Montepara, Tebaldi, Marradi, Betti (2012) [8] "Effect of payment performance of a sub-base layer composed by natural aggregate and RPM." The research conducted on a specially designed test track aimed to evaluate the effects of incorporating a sub-base layer mixture composed of 50% natural aggregates and 50% Recycled Pavement Material (RPM) on pavement performance. The study's conclusions emphasize the various advantages of RPM recycling, particularly in terms of economic enhancement, transportation infrastructure improvement, and the creation of job opportunities. Furthermore, the utilization of RPM in pavement construction and maintenance promotes labour-based practices, contributing to job creation and fostering overall economic growth. These initial findings suggest that incorporating RPM into pavement projects could have positive economic and social impacts, making it a promising and sustainable option for future infrastructure development and maintenance.

Khushbu M. Vyas, Shruti (2013) [9] "Technical viability of using Reclaimed Paving Materials in

Ahmadabad BRTS Corridor for Base Course" The key findings from the laboratory investigation are as follows: To achieve the desired gradation, trials were conducted by incorporating 60% RPM mix, 30% aggregates of 40 mm size, and 10% stone dust. The Aggregate Impact Value was determined to be 14.89%, while the Combined Flakiness and Elongation index was found to be 27.64%. These values were below the maximum permissible limits of 30% as specified by MoRTH for the Wet Mix Macadam (WMM) base course, indicating satisfactory material performance. The study measured the specific gravity of the aggregates, which fell within the range of 2.8 to 3.0. Additionally, the water absorption of the aggregates was found to be within the specified limits of 0.3 to 2.0%. These findings demonstrate that the material met the specified requirements, indicating its suitability for the intended use. In summary, the specific gravity and water absorption values of the aggregates were within acceptable ranges, confirming that the material is suitable for the intended application in the study.

Sharma Jitender, Singla Sandeep (2014) [10] "Study of Recycled Concrete Aggregates" This paper provides an overview of the introduction and production process of recycled concrete aggregates (RCA) and delves into their diverse applications in the construction industry. The properties of recycled aggregates are thoroughly examined and compared with those of natural aggregates. The research findings highlight that recycled aggregates offer promising potential for various construction applications. One of the significant applications of recycled aggregates is in aggregate base courses, which play a critical role as a structural foundation for roadway pavements. The study reveals that these untreated recycled aggregates can be effectively utilized in constructing foundations for paving projects, demonstrating their practicality and suitability for such applications. In conclusion, the paper emphasizes the versatility and benefits of using recycled concrete aggregates in construction projects, particularly for aggregate base courses, contributing to sustainable practices and resource conservation in the construction industry.

Singh Veresh P., Mishra Vivek, Harry N. N. and Bind Y. K. (2014) [11] "Utilization of Recycled Highway Aggregate by Replacing it with Natural Aggregate" For this study, a modified Proctor CBR test was conducted on five different mix batches. Each batch included replacement levels of 0%, 10%, 20%, 30%, 40%, and 50% of fresh aggregate with recycled aggregate at their respective optimum moisture contents. The results indicate that, up to a 30% replacement level, the maximum dry density of the recycled aggregate matrix is approximately 0.01 g/cc higher compared to the reference mix containing natural aggregate. However, the CBR of the recycled aggregate matrix at the same replacement level is approximately 1% lower than the reference mix with natural aggregate. This reduction in strength could be attributed to the relatively lower strength of the recycled aggregate in comparison to fresh aggregate. These findings suggest that while the maximum dry density of the recycled aggregate matrix slightly increases, there is a slight decrease in the CBR value compared to the reference mix. The lower strength of the recycled aggregate might account for this reduction in strength.

Rao Maulik, Shah N.C. (2014) [12] "Utilization of RPM (Reclaimed Asphalt Pavement) Material Obtained by Milling Process" This practical study demonstrates the significant influence of replacing virgin materials with Reclaimed Paving Materials (RPM) in various road construction applications. The findings indicate that by incorporating 20%, 40%, and 60% RPM into black cotton soil, the California Bearing Ratio (CBR) values increase by 2%, 3.8%, and 6.8%, respectively. This improvement in CBR values suggests that the use of RPM can effectively enhance the subgrade performance. Moreover, the study reveals substantial savings in virgin materials by utilizing RPM. Specifically, a reduction of 25% in virgin material can be achieved for GSB Grade-II, while a 35% reduction is possible for Wet Mix Macadam (WMM). This demonstrates the potential cost and resource savings associated with incorporating RPM into road construction projects.

Sreedhar N, Mallesha K. M. (2014) [13] "Cost Analysis of Low Volume Rural Roads using RPM Materials as G.S.B." In summary, the abundance of R.A.P. generated from road expansion and upgrades presents an opportunity to address both the disposal of industrial waste and the conservation of natural resources. By incorporating R.A.P. materials in the G.S.B., significant cost savings can be achieved, offering a sustainable solution for road construction projects. Incorporating R.A.P. materials in the Granular Sub Base (G.S.B.) also leads to construction cost savings of approximately 25-30%. By analysing the cost implications, it has been determined that implementing R.A.P. materials in a 5 km stretch can result in savings of up to 35%.

Singh Jaspreet, Singh Jashanjot, Duggal A. K. (2015) [14], "A Review paper on Reclaimed Paving Materials (RPM)", In the construction of flexible pavements, it is feasible to adopt RPM in various layers, ranging from 20% to 50% of the total mixture. By utilizing RPM, we can effectively reduce the consumption of new asphalt materials while still maintaining the desired performance and structural integrity of the pavement. This approach not only reduces the environmental impact associated with the disposal of old pavement materials but also contributes to the preservation of natural resources. The incorporation of RPM in different layers of flexible pavements is a viable solution that offers economic, environmental, and sustainability benefits. It provides an opportunity to make efficient use of existing materials, reduce construction costs, and minimize the demand for virgin resources.

Singh Jaspreet, Duggal A. K. (2015), [15] "An Experimental study on Reclaimed Paving Materials (RPM) Dense Bituminous Macadam" The findings of this study indicate that incorporating RPM in asphalt mixes can yield comparable or even superior results compared to virgin mixes. Again, this study concludes that a 30% RPM content in the mix exhibits similar performance to that of a virgin bituminous mix and outperforms other RPM percentages tested. Additionally, by incorporating 30% RPM mixes in a project, a significant cost reduction of 21% can be achieved. As the utilization of RPM continues to gain traction in India, it holds promise as a sustainable and economically viable solution for the construction industry.

In conclusion, the recycling of bituminous pavements has evolved into a well-established and effective methodology for the rehabilitation and construction of pavements. Originating in the early 20th century, the approach gained significant momentum in the 1970s due to rising bituminous prices. Extensive research has demonstrated the comparable performance of high RPM mixtures, affirmed their viability, and encouraged the industry to embrace recycling practices. The adoption of recycling not only reduces construction costs but also supports environmental sustainability by conserving resources and minimizing waste generation.

## 3. Conclusion

The percentage of Reclaimed Paving Materials (RPM) used in road construction projects varies depending on the project and the condition of the RPM materials. It has been successfully used up to 70% in certain road projects. It is not advisable to prepare a blending mix with 100% use of RPM. The large size of aggregates in the RPM mix tends to be deficient due to the crushing and aging process. The utilization of recycled aggregate in granular sub base (GSB) for road construction offers both economic advantages and environmental benefits by mitigating mining pollution. The ideal proportion of Reclaimed Paving Materials (RPM) in granular mixes does not have a fixed and universally applicable percentage. Instead, different road projects have successfully employed varying percentages of RPM based on their unique specifications and needs. Recycling aggregates from demolition projects can save costs associated with transporting the material to landfills and disposal.

These conclusions highlight the feasibility and advantages of utilizing RPM in road construction, while also emphasizing the need for careful consideration of factors such as RPM percentage, aggregate size, and strength criteria to ensure the successful implementation of RPMbased granular sub-base in village road projects. Overall, the adoption of recycled aggregate in GSB for road construction provides a dual advantage of cost savings and environmental sustainability. By embracing this approach, the industry can contribute to minimizing mining pollution while reaping the economic benefits offered by the utilization of recycled materials.

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# 12. Optimized water supply network design for rural West Bengal: A case study

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#### Abstract

The present study attempts a to propose an optimized water supply network for rural region in West Bengal, India. The evaluation and planning the water distribution network in this area, was performed using the EPANET software. This software is instrumental in devising water distribution systems for a wide range of applications, whether it's for residential usage or commercial purposes. EPANET, encompassing a computer program, conducts simulations to analyses hydraulic and water quality behaviours within pressure pipe networks. The analysis of the distribution network hinges on diverse factors such as public demands, inflow and outflow quantities from overhead reservoirs. This analysis yields insights into various demands, losses, and overall public consumption. Crafting a new supply network not only makes the local administration cognizant of emerging demands but also the pace of demand escalation. The design is tailored while considering the projected population growth rate and the village's developmental trajectory. This design culminates in an enhancement of the existing network's effectiveness.

Keyword: Water Distribution Network, Water Demand, EPANET software.

# 1. Introduction

The planning and design of a water supply distribution network holds a pivotal role within the realm of urban and municipal development. This critical responsibility rests in the hands of city planners and Civil Engineers, who approach this task with meticulous attention, taking into account a multitude of influential factors (Alperovits and Shamir 1977). These factors encompass the geographical location of the town or city, the existing demand for water, the projected growth in demand, potential leakages within the conduit system, the requisite pressure within pipes, and the possible losses within the pipeline network (Adedeji et al. 2022; Alemu and Dioha 2020; Merga and Behulu 2019).

The water supply system sources water from a diverse range of origins, embracing both groundwater and surface water. This acquired water then undergoes a series of transformative stages, including purification, disinfection, and chlorination. Subsequent to these treatments, the refined water is channelled towards elevated reservoirs or tanks, strategically positioned as entry points into the extensive web of water distribution (Van Koppen, Moriarty, and Boelee 2006; Visscher 2006). This intricate network is purposefully designed to fulfil a wide spectrum of needs, ranging from the fundamental act of drinking to the aspects of cleaning, sanitation, irrigation, and firefighting, among other crucial utilities. The overarching objective of this distribution framework is the widespread accessibility of water, reaching into households, industrial establishments, and public spaces alike (Butterworth, Sutton, and Mekonta 2013; Nwankwoala 2011). The demand for an adequate volume of water, coupled with the essential pressure levels, is imperative at every juncture. This mandates the elaborate transportation of

water through city thoroughfares, ultimately reaching individual residences.

The complex task of conveying water from treatment facilities to homes is executed seamlessly through a meticulously organized distribution system. This system comprises pipes of varying dimensions, entrusted with the responsibility of transporting water to the streets, aided by valves adept at regulating the flow. The system further integrates service connections tailored for individual households, while reservoirs assume a pivotal role in the storage of water earmarked for introduction into the distribution pipes. The distribution process may adopt one of two strategies: either water is directly pumped into the pipes or it's initially stored within reservoirs before being gradually released into the expansive distribution network.

Typically, the design of distribution networks accounts for peak demand scenarios, which can consequently lead to reduced flow rates in certain segments. This situation has the potential to compromise the chemical and microbial quality of the water supply. Therefore, the primary objective of the distribution network revolves around ensuring a consistent and sufficient supply of water, characterized by both appropriate pressure and optimal flow rates. A multitude of factors come into play here, including elements like pipe wall friction, pipe length, diameter, gradient, and the overall water demand, all contributing to the phenomenon of pressure reduction. In a conventional approach, water distribution networks are designed in alignment with the city's street layout and the natural topographical features. However, thanks to the integration of software tools, modelers are able to simulate the intricate interplay of pressure dynamics and flow patterns within these networks.

Within the context of distribution network analysis, the pivotal EPANET software (Rossman 2000) emerges as the chosen tool (Ramana, Sudheer, and Rajasekhar 2015; Sayyed, Gupta, and Tanyimboh 2014). This software serves as a digital representation of a model, specifically designed to encompass the intricacies of water distribution networks. It engages in sophisticated simulations, spanning extended timeframes, to capture the intricate movements of water and its quality dynamics within the complex network of pipes. The essential constituents of this pipe network encompass a variety of components, including conduits, junctions (nodes), pumps, valves, and containers such as storage tanks or reservoirs. This software assumes the role of vigilant oversight, monitoring water flow through each conduit, gauging pressure at every junction, measuring water levels within tanks, assessing chemical concentrations during transportation, tracking the age of water, deciphering its origin, and mapping its trajectory throughout the designated duration of simulation(Mohapatra, Sargaonkar, and Labhasetwar 2014). The core objective remains consistent throughout: to ensure a satisfactory water pressure level at various crucial points, encompassing the very endpoints where consumers receive their supply. In parallel, this software fosters adaptability within the distribution process, allowing for dynamic adjustments concerning the distribution mechanisms and the relative elevation of installations in relation to water treatment plants (Arunkumar and Mariappan 2011).

#### 2. Study Area

The water distribution system design pertains to the region known as Bahira Village. Bahira Village, with a population of 2807 individuals, ranks as the 7th most densely populated village within the North 24 Parganas sub-district. It is situated in the North 24 Parganas district of the West Bengal state in India. Encompassing an area of 10 km<sup>2</sup>, Bahira Village holds the position of the 6th largest village in terms of land area within the sub-district. The population density of this village stands at 291 persons per km2. The settlement comprises 745 households. Administrative governance falls under the Bahira Panchayat. The village's proximity to the sub-district headquarter, North 24 Parganas, is 7 km, while the district headquarter, Kali Bari, is located 21 km away. The devised distribution system here takes the form of a tree system, also referred to as a dead-end system.

# 3. Methodology

#### 3.1 Surveys and Maps

The land stretch extending from the water source to the target location undergoes surveying to determine elevation levels for aligning the primary pipeline. This pipeline serves as the al sectors, gardens, and more, a thorough survey of the distribution area is conducted. This process involves generating a topographical map of the region, aiding in the identification of elevated and lower regions within the area.

#### 3.2 Tentative Layout

Subsequently, a preliminary arrangement for the distribution pipeline is outlined, encompassing the placement of the treatment facility(ies), distribution mains, distribution and equilibrium reservoirs, valves, hydrants, and related components. The entirety of the region is subdivided into distinct distribution sectors. Additionally, the population density (average number of individuals per hectare of land) is indicated. An effort is made to minimize the length of pipelines, aiming to keep them as concise as feasible.

#### 3.3 Calculation of Pipe Diameters

Once the designated discharge for the design is established, pipe diameters are selected in a manner that ensures flow velocities fall within the range of 0.6 to 3 m/s. Lower velocities are assigned to pipes with smaller diameters, while larger diameters correspond to higher velocities. Subsequently, the head loss within the pipes is computed utilizing Hazen-Williams formula (or monogram), as depicted in equation 1 (Anisha et al. 2016).

 $V = 0.849 \times C \times R^{0.63} \times S^{0.54}$ (1)

The provided equation encapsulates the relationship between various key factors governing the flow of water within a pipe. In this equation, the variable "V" signifies the average velocity of the water current coursing through the pipe in meters per second (m/s). The hydraulic radius, denoted by "R," encompasses the concept of the mean depth of the flow, representing the average distance between the water surface and the pipe's bottom. This hydraulic radius, expressed in meters (m), provides crucial insight into the flow dynamics. The term "S" signifies the hydraulic gradient, signifying the change in elevation experienced over a specific distance. This gradient is dimensionless and helps quantify the incline or decline of the pipe. The coefficient "C" embodies the roughness of the pipe's inner surface, a critical factor influencing water flow resistance due to surface characteristics. This dimensionless coefficient works in conjunction with the other variables to determine the extent of friction within the pipe.

When the equation is expressed in terms of the pipe's diameter, represented as "D," it takes on a more simplified form (Eq.2). This transformation helps in practical applications where the diameter is a readily available parameter. This equation, in its simplified representation, serves as a fundamental tool for engineers and experts in hydraulic systems, enabling them to gauge and predict flow behavior within pipes while considering diameters and hydraulic characteristics.

$$V = 0.354C \times D^{0.63} \times S^{0.54}$$
(2)

Where, D is the diameter of the pipe in meters. Expressed in terms of loss of head and the length of the pipe, the Hazen Williams formula takes the following form:

$$h_f = 6.843 \times [L/(D^{1.167})] \times [V/C_H]^{1.852}$$
 (3)

The discharge Q (m<sup>3</sup>/s) is given by: Q =  $0.278CD^{0.63}S^{0.54}$ 

# 4. Results and Discussion

The findings derived from the implementation of the EPANET software for Bahira Village have been subjected to a meticulous evaluation, forming a significant part of the results and analysis section. The Figures 1 and 2 represents the key parameters before optimization of the network respectively. The pressures optimized through the EPANET software align seamlessly with the guidelines prescribed in the Comprehensive Public Health (CPH) Manual, underscoring the software's accuracy and adherence to regulatory standards (Figure 2). The absence of negative pressure occurrences at any junction or node was a conspicuous observation, which indicates seamless flow of water in the desired direction. Impressively, all pressure values exceeded the recommended 7-meter threshold set by the CPH

Manual, ensuring the network's compliance with safety standards.



Figure 1: Representation of Base demand, pressure and elevation at different nodes before optimization



Figure 2: Representation of Base demand, pressure and elevation at different nodes after optimization

Similarly, Figures 3, 4 and 5 represents the velocity, head loss and diameter at different lengths before and after the optimization technique was used. The distribution of pipe diameters within the network exhibited significant variability. The smallest diameter measured 45.2 millimeters (mm), while the most expansive reached 126 mm. The optimization of diameter at different length has significant impact on parameters such as velocity and head loss through the pipe. The general observation from these figures suggest that the application of the optimization technique has reduced average velocity and velocity fluctuation at different lengths through the pipe. The average velocity of water flow within the pipes was quantified at 0.34 meters per second (m/s). Further the application of the optimization technique has also significantly reduced the head loss at different length of the network. The study revealed an average head loss of 3.63 meters per kilometer (m/Km) across the network's pipes, thereby

making the network much more efficient for the water supply.



Figure 3 Comparison of velocity corresponding to different length before and after optimization of the network.



Figure 4 Comparison of Unit head loss corresponding to different length before and after optimization of the network.



Figure 5 Comparison of Diameter corresponding to different length before and after optimization of the network.

In summation, the meticulous assessment of outcomes from the EPANET software provides a comprehensive understanding of Bahira Village's distribution network performance. The software's precision in conforming to CPH Manual standards, coupled with its ability to extract crucial parameters such as pressure, velocity, head loss, and pipe dimensions, underscores its indispensable role in hydraulic analysis and network optimization.

# 5. Conclusion

The results obtained through the utilization of the EPANET software for Bahira Village have undergone thorough evaluation. The computed pressures, as ascertained by the EPANET software, align impeccably with the stipulations outlined within the Comprehensive Public Health (CPH) Manual. The comprehensive analysis has unveiled the subsequent key findings:

- 1. At no point were instances of negative pressure detected within any junction or node. In fact, the entire spectrum of pressure values notably surpasses the recommended threshold of 7 meters, as laid out by the CPH manual.
- 2. The average velocity of water flow within the pipes emerged as a quantifiable value, calculated to be 0.34 meters per second (m/s). This parameter offers essential insights into the flow dynamics within the network.
- 3. The analysis disclosed an average head loss traversing the expanse of the pipes, accounting for a measurement of 3.63 meters per kilometer (m/Km). This measurement is a crucial indicator of energy losses within the system.
- 4. Within the intricate web of the network, the diameters of the pipes exhibit a range of variability. The smallest diameter within the network was gauged at 45.2 millimeters (mm), while the most extensive diameter reached a maximum of 126 mm. This spectrum of diameters influences flow capacity and fluid dynamics within the system.

In essence, the assessment of outcomes from the EPANET software offers a comprehensive overview of the distribution network's performance in Bahira Village. The software's precision in compliance with the CPH Manual guidelines, coupled with its ability to uncover critical parameters such as pressure, velocity, head loss, and pipe dimensions, serves as a testament to its indispensable role in hydraulic analysis and network optimization.

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# 13. Applicability of random forest model for predicting groundwater table in Birbhum District, West Bengal India

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## Abstract

Accurate groundwater predictions are vital for managing water resources essential for agriculture, daily life, and economic growth. The present study attempts to develop a Random Forest model (RF) to predict groundwater levels for two well stations (Bahari, Nanur) in Birbhum district, West Bengal, using data from the Central Groundwater Board (CGWB) portal. The dataset was split into a training set (1996-2016) and a testing set (2017-2021). The performance of RMSE, MSE, and R<sup>2</sup> values for Bahari and Nanur station was 2.13, 4.56, and 0.88 and 2.17, 4.744, and 0.839 respectively. The accuracy of RF model was found to be satisfactory. This suggests that the RF model could assist decision-makers in devising sustainable groundwater levels, indicating a more critical condition in terms of groundwater depletion compared to Nanur. Thus, this study offers a practical method for groundwater level prediction, aiding long-term management strategies.

Keywords: Groundwater, Machine learning, Artificial intelligence, Groundwater quantity

# 1. Introduction

The increasing demand for fresh water has been amplified by the critical role groundwater plays as one of the world's most essential resources. Groundwater is predominantly utilized for agricultural, industrial, and domestic purposes. Furthermore, factors such as a growing global population, industrialization, and the impacts of climate change, including irregular or reduced monsoons and extended summers, have contributed to a surge in water requirements in urban and rural areas (Qadir et al. 2007; Wada et al. 2010).

The groundwater level (GWL) serves as a straightforward and immediate indicator of groundwater's presence and ease of access. A comprehensive comprehension of GWL trends spanning historical, present, and future contexts equips policymakers and water industry professionals with enhanced understanding and foresight. This, in turn, empowers them to formulate well-informed strategies for effective water resource planning and management, ultimately facilitating sustainable socio-economic development (Wada et al. 2010). Nonetheless, the groundwater level (GWL) is a complex outcome resulting from the interplay of numerous climatic, topographic, and hydrogeological factors, and their intricate interactions. This complexity adds a layer of difficulty to the task of simulating GWL(Afzaal et al. 2019; Sadeghi-Tabas, Samadi, and Zahabiyoun 2017).

The rise in water demand for irrigation is a direct consequence of the population growth's impact on food production. In many regions, groundwater levels have witnessed a steady decline over recent decades due to excessive groundwater extraction to meet the escalating irrigation needs. Unintentionally, the proliferation of pumping wells has been driven by the heightened water demands of various sectors, encompassing residential, agricultural, and industrial sectors. Nonetheless, excessive groundwater exploitation gives rise to a myriad of technical and socioeconomic challenges, such as the over-extraction of aquifers, deterioration of groundwater quality, and the drying up of wells. Therefore, it is imperative to implement comprehensive groundwater development plans to maintain a harmonious equilibrium in the groundwater environment (Laveti et al. 2021a; 2021b).

Numerous research endeavours have been undertaken employing various simulation methodologies to predict groundwater levels both quantitatively and qualitatively. Traditionally, modelling groundwater levels has been carried out using a physical model known as MODFLOW. However, this method has practical limitations, particularly when dealing with limited data availability, where precise predictions take precedence over understanding the underlying mechanisms. In such scenarios, black-box artificial intelligence models offer a viable alternative. These methods encompass a diverse spectrum of approaches, including physically based conceptual models and experimental models (Gupta, Yadav, and Yadav 2019; Izady et al. 2014; Xue et al. 2018).

Groundwater modelling involves several established approaches, such as finite difference (Omar et al. 2019), finite volume (Jamin et al. 2020), finite element (Ukpaka, Adaobi, and Ukpaka 2017), and element-free(Pathania et al. 2019) methods. While these traditional models are known for their robustness and reliability, their precision and accuracy are constrained by several factors. These limitations include a heavy reliance on extensive datasets concerning aquifer properties, the geological characteristics of porous media, and basement topography (Barnett et al. 2012). Additionally, tasks such as delineating domain boundaries, selecting an optimal grid size for solving differential equations, and calibrating/validating the model contribute to the complexity and sophistication of numerical modelling.

In the past two decades, artificial intelligence (AI) models have gained widespread usage to address the shortcomings of conventional numerical models in groundwater level (GWL) simulation. It's worth noting that around 70% of areas have not ventured into GWL studies due to factors like abundant surface water or sparse populations, as observed in polar regions, Russia, and similar areas. Additionally, underdeveloped regions such as Africa, parts of Asia, and North America may not have fully explored AI techniques (Tao et al. 2022).

There has been a substantial increase in research efforts in this field in recent years. However, there is a need for further studies encompassing diverse geographical locations to assess the efficacy of proposed AI models. The utility and reliability of AI models in tackling complex and high-dimensional engineering problems have been well-established over the past few decades (Bhagat, Tung, and Yaseen 2020; Jiang et al. 2017). AI encompasses multidimensional systems that amalgamate various mathematical and statistical components, alongside arithmetic and heuristic algorithms. Its applications extend across a wide spectrum of scientific and engineering domains, including energy, robotics, economics, and civil and environmental engineering (Beyaztas et al. 2019; Hai et al. 2020; Salih, Alsewari, and Yaseen 2019). In the realm of civil and environmental engineering, AI has found extensive use in addressing various challenges, including the utilization of soft computing techniques (Fadaee, Mahdavi-Meymand, and Zounemat-Kermani 2022), Machine Learning (ML) methods (Guzman et al. 2015; Jamei et al. 2020; Yaseen et al. 2018), probabilistic analysis (Zhu et al. 2019), and Fuzzy-based systems (Zounemat-Kermani and Scholz 2013). In recent times, increased attention has been devoted to the successful application of AI in various hydrological fields, spanning water resources (Yaseen et al. 2019), surface and groundwater hydrology (Adnan et al. 2020), sediment contamination(Bhagat, Tung, and Yaseen 2021), and hydraulics (Mahdavi-Meymand and Zounemat-Kermani 2020). The present study attempts to evaluate the performance measures of a simple Random Forest algorithm developed to predict the ground water table in Birbhum district, India.

# 2. Methodology

# 2.1 Study Area and Data Collection

Birbhum is a district situated in the southwestern region of West Bengal, extending between the latitudes 23° 32' 30" and 24° 35' 0" north and the longitudes 88° 1' 40" and 87° 5' 25" east. It is bounded by the Ajay River and shares its borders with Santhal Paraganas, Murshidabad, and Burdwan. Encompassing an area of 4545 square kilometers, Birbhum experiences a typical seasonal climate. The primary focus of our study is the Bolpur sub-division within Birbhum, renowned for its extensive agricultural activity and noteworthy groundwater depletion issues. For our research, we have chosen two well stations, Bahari and Nanur, within this sub-division, with Bahari being notable for recently recording the deepest groundwater levels.

# 2.2 Random Forest (RF)

The Random Forest method is a supervised machine learning technique built upon the foundation of the decision tree algorithm. It is employed to address both regression and classification problems by utilizing ensemble learning, a method that combines multiple classifiers to tackle complex challenges. Within a Random Forest algorithm, several decision trees constitute the 'forest.' This forest is trained using bagging or bootstrap aggregation, a technique that enhances the accuracy of machine learning models.

The algorithm's predictions rely on the outcomes of these decision trees. The predictions from various trees are averaged or aggregated to generate final predictions. As the number of trees increases, the accuracy of predictions improves, and the risk of overfitting the dataset decreases. Random Forest effectively mitigates the issues associated with individual decision trees while boosting precision. Decision trees serve as the fundamental building blocks of Random Forest algorithms. Decision trees are a decision support tool structured like a tree. They consist of three key components: the root node, decision nodes, and leaf nodes. The decision tree algorithm divides a training dataset into

branches, which further split into additional branches until a leaf node, representing the decision tree's outcome, is reached. Attributes used to forecast outcomes are indicated by the nodes within the decision tree. Decision nodes establish links to the leaf nodes, and the various types of nodes within the decision tree are illustrated in the diagram. The dataset underwent a partition into two distinct subsets: a training dataset, constituting 70% of the total data, and a testing dataset, comprising the remaining 30%. The training dataset encompassed information spanning from January 1996 to December 2016, while the remaining data were exclusively reserved for the testing phase. Within the boundaries of the training dataset, an intricate Random Forest model was meticulously crafted, with a thorough optimization process applied to fine-tune its hyperparameters. This model was composed of a total of 100 decision trees, each constrained by a maximum depth of 10 levels. Additionally, to facilitate node splitting, a prerequisite of a minimum of 2 data points was imposed. Furthermore, every leaf node within the tree structure was mandated to contain a minimum of 1 data point.

# 3. Results and Discussion

Groundwater data specific to the Bahari and Nanur stations was collected across various seasons and subsequently compared with predictions generated using a Random Forest model. The results predicted using machine learning technique were compared in Figure 1. The predicted data using the Random Forest technique was found to follow the trend of the observed data for both the stations. These visual representations provide insights into the performance and accuracy of the developed Random Forest model. To evaluate the model's performance on using performance indices such as Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and R-squared  $(R^2)$  score. (Table 1). The values of all these performance indices suggests that the developed Random Forest model was able to learn accurately from the input data and it was able to predict the data with significant accuracy.


Figure 1 Comparison between the observed groundwater data and predicted data for (a) Bahari (b) Nanur

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Station	MSE	RMSE	R2
Bahari	4.56	2.13	0.88
Nanur	4.744	2.17	0.839

The observation from the present study suggests that the Random Forest model can be considered as a powerful and reliable tool for the predicting of groundwater table elevation. considering the complexities and difficulties involved with this undertaking through experimental and theoretical model, these types of models can be of great help for the policy makes and researchers. Further, the Random Forest model is quite easy to implement, does not involved significant computational cost and has very few hyperparameters. Therefore, the model is also relatively easy to set up.

# 4. Conclusions

In the present study, we developed a machine learning model for predicting groundwater levels at two observed wells in Birbhum, West Bengal. Based on the model performance assessment, the accuracy of the Random Forest (RF) model was found to be satisfactory. The RF model offers several advantages, including potential application to historical datasets, accurate groundwater level predictions, and a valuable tool for hydrologic field specialists, practitioners, and regions with similar hydro-climatic conditions worldwide. Analysing the predicted data for all stations, we found that Bahari station consistently exhibited the deepest predicted groundwater level compared to the other stations. This analysis suggests that Bahari faces a more critical situation in terms of groundwater depletion compared to Khagra and Nanur.

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# 14. Review paper on eccentric wings in bridge deck

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#### Abstract

A passive aerodynamic tool for accelerating bridge flutter speed is the eccentric-wing flutter stabilizer. The stabilizer has stationary wings that are placed outside of the bridge deck to create aerodynamic dampening and speed up the flutter. Through the use of non-dimensional factors, this work performs parametric flutter analysis while also altering bridge characteristics and wing shapes. The proportionate increase in flutter speed brought on by the wings was highlighted in a graphic representation of the findings. Torsional divergence was taken into account when doing generalized two-degree-of-freedom flutter studies and multi-degree-of-freedom analyses. A simplified two-degree-of-freedom technique and methodologies for determining flutter speed utilizing a finite aeroelastic beam element are presented. The Taco-ma Narrows Bridge is used as an example in the study to discuss a single-degree-of-freedom analysis for torsional flutter.

Keywords: Eccentric-wing flutter stabilizer, Bridge flutter speed enhancement, Passive aerodynamic devices, Long-span bridge design, Stationary wings, Lateral eccentricity, Parametric flutter analysis, Wing configurations

# 1. Introduction

Bridges are subjected to various wind-related effects, including static wind forces, buffeting, vortex shedding, and flutter. Unlike the first three effects, which pertain to the mechanical response of the bridge, flutter is a critical stability issue resulting from wind-induced motion forces and can potentially lead to abrupt structural failure. Flutter analysis is a significant aspect of designing and budgeting for longspan bridges. In the detailed design phase, engineers must take all these effects into account. Advanced methods, as outlined by Abbas et al. (2017), have been employed to predict the combined impact of buffeting, vortex shedding, and motion-induced forces, and these methods can also incorporate aerodynamic and structural nonlinearities using time-domain approaches.

It is frequently sensible to put the flutter analysis first and postpone taking other wind effects into account until later phases of the conceptual design of an especially long-span bridge. Commonly, a frequency domain examination of pure flutter is performed. Theodorsen's 1934 air foil flutter theory, which uses intricate functions to describe erratic aerodynamic forces on a thin flat plate and determines the essential wind speed for flutter onset (flutter speed), provided the theoretical underpinnings for this strategy. This hypothesis was modified for bridge flutter in 1971 by Scanlan and Tomko. They used empirical real functions discovered from the testing of sectional bridge-deck models in a wind tunnel rather than closed-form complex functions to represent unstable aerodynamic forces.

Twodegreesoffreedom—heave, and rotation along with the initial vertical bending and torsional modes of vibration are used to model the spatial behaviors of the bridge. As mentioned by Starossek (1993), Vu et al. (2011), and Tamura and Kareem (2013), when this simplification is inadequate, more sophisticated multimode and finite element approaches are available. The research by Matsumoto et al. (2010) and Vu et al. (2015) indicates that while it is possible to include the lateral motion of the bridge deck, it typically has little impact on the computed flutter response of the bridge. The installation of lateral eccentric wings parallel to the bridge deck by engineers can reduce flutter. Figure 1 shows how these wings are rigidly fastened to the deck using longitudinally spaced support structures at predetermined intervals. This arrangement creates an eccentric-wing flutter stabilizer, a passive aerodynamic device. The wings cause the motion of the bridge deck to be aerodynamically dampened, which raises the flutter speed. An important point to note is that the advantage of using eccentric wings is that the dampening effect on the rotational motion of the bridge deck is precisely proportional to the square of the wing's eccentricity. These claims are supported by wind tunnel testing and flutter studies, as discussed by Starossek et al. (2018). When appropriately modified, the eccentric-wing flutter stabilizer idea can also be used to stabilize

The primary objective of incorporating stationary wings to stabilize bridges against flutter is to generate sufficient aerodynamic damping, thereby effectively increasing the flutter speed. These wings, along with their support structures, constitute a passive aerodynamic device known as an eccentric-wing flutter stabilizer. This device plays a critical role in producing aerodynamic damping that affects the motion of the bridge deck, ultimately increasing the flutter speed.

A key advantage of using eccentric wings is that they lead to a quadratic increase in the damping effect on the rotational motion of the bridge deck. This quadratic relationship between wing eccentricity and damping explains why eccentric wings are preferred for flutter stabilization.

To reduce flutter in bridges, stationary wings are used to create enough aerodynamic damping and consequently raise the flutter threshold velocity. This is achieved using an eccentric-wing flutter stabilizer, a passive aerodynamic device made up of wings and the supports that go with them. The flutter threshold velocity is raised as a result of the stabilizer's aerodynamic dampening of the bridge deck's motion. Notably, the dampening of the rotating movement of the bridge deck is precisely equal to the square of the eccentricity of the wing, emphasizing the positive effects of greater eccentricity. The article describes numerous mathematical methods for estimating the flutter velocity of bridges that have been stabilized against flutter with stationary wings. These techniques include a multi-degree-of-freedom (MDOF) flutter analysis method, a finite aeroelastic beam element technique, and a quasi-steady flow methodology. However, the two-degree-of-freedom (2-DOF) flutter analysis methodology, which takes into account the complex interplay between the translational and rotational degrees of freedom of the bridge deck, is the most sophisticated and thorough technique described in the paper.

When initiating the conceptual design of an extraordinarily long-span bridge, it is often prudent to prioritize the analysis of flutter while postponing the consideration of other wind-related factors until later stages. As a result, the analysis described in this article deliberately omits the examination of additional wind effects such as buffeting, vortex shedding, and static gusts.

# 2. Literature Review

Flutter Resistance Enhancement: The text explores the use of lateral eccentric wings rigidly attached to bridge decks to increase flutter resistance. Influence of Wing Configuration: The length, width, and eccentricity of the wings play crucial roles in determining the effectiveness of flutter resistance. The over-proportional influence of wing eccentricity and width on flutter resistance is noted. Aesthetic and Economic Considerations: The text acknowledges concerns about the aesthetic quality of bridges with large eccentric wings. It suggests that wings with more moderate eccentricity can address aesthetic concerns while still being effective in reducing flutter speed. Torsional Divergence: In some cases, torsional divergence may govern flutter behaviour instead of the wings. In such cases, it is advisable to lower the flutter speed increase produced by the wings to match the divergence speed for economic reasons. Cost-Efficiency: The cost associated with increasing flutter speed using eccentric wings is found to be relatively low compared to the overall cost of the bridge. Effect on Different Bridge Types: The flutter

resistance augmentation depends on the characteristics of the bridge and works best for light bridges with low torsional-to-vertical frequency ratios. Flutter Analysis Generalization: Both two-degree-of-freedom (2-DOF) and multi-degree-of freedom (MDOF) flutter analyses are used in the study to validate results. It implies that 2-DOF analysis is applicable when the bridge length is shorter than the wing length. To increase the flutter speed of long-span bridges, the eccentric-wing flutter stabilizer, a passive aerodynamic device, is discussed in the study. To address aesthetic concerns while preserving cost-effectiveness, this device's wings are oriented less eccentrically and are mounted parallel to the bridge deck. Because its wings do not move relative to the stabilizer, the eccentric-wing flutter stabilizer is different from earlier designs.

The study uses parametric flutter analysis to explore the impact of both bridge properties and wing configurations, summarized in non-dimensional quantities. The goal is to find a balance between flutter resistance and aesthetics. The analysis is based on classical bridge flutter theory, assuming steady-state harmonic vibration and non-turbulent wind. The input parameters for the bridge include the frequency ratio, mass ratio  $(\mu\mu)$ , the reduced mass radius of gyration, and the damping parameter. These parameters define the structural properties of the bridge. The properties of the wings are characterized by their relative eccentricity, relative width, relative length, and relative mass. The paper highlights the concept of torsional divergence, where the bridge experiences instability due to torsional motion. It is shown that for certain parameter combinations, torsional divergence can become the governing factor over flutter, limiting the effectiveness of the wings. Previous results from the authors' studies reveal that large eccentricity wings are highly effective in increasing flutter resistance but raise concerns about aesthetics. The paper introduces reduced eccentricity wings to address these concerns while maintaining effectiveness. The analysis indicates that reduced eccentricity wings can still significantly raise flutter resistance, albeit to a slightly lesser extent than high eccentricity wings. Renderings of bridges equipped with these reduced eccentricity wings are presented to demonstrate that such configurations can be aesthetically pleasing. The authors emphasize that concerns about the visual impact of the eccentric-wing flutter stabilizer

can be mitigated through thoughtful design and reduced eccentricity. In conclusion, the paper underscores the potential of eccentric-wing flutter stabilizers as a cost-efficient solution to increase the flutter speed of long-span bridges. By reducing wing eccentricity and, if necessary, wing length, the aesthetic concerns associated with large eccentricity wings can be addressed. The renderings of bridges equipped with these stabilizers exemplify how functionality and aesthetics can coexist in bridge design, making this passive aerodynamic device a viable option for enhancing bridge safety and performance (1).

This paper focuses on the aerodynamic stability of long-span bridges, particularly addressing the critical issue of flutter—a stability problem caused by motion-induced wind forces that can lead to abrupt bridge collapse. While considering various wind effects such as static wind force, buffeting, and vortex shedding is crucial in the detailed design of long-span bridges, this paper highlights that flutter analysis takes precedence, especially for extended bridge spans.

The primary analysis method employed is in the frequency domain, drawing inspiration from Theodorsen's air foil flutter theory. Instead of using complex functions, the study relies on empirical real functions derived from wind tunnel experiments conducted with sectional bridge deck models to describe unsteady aerodynamic forces. The spatial system is simplified into two degrees of freedom: heave and rotation, utilizing the initial vertical bending and torsional modes of vibration. For more intricate scenarios, multimode and finite element approaches are available.

An innovative concept introduced in the paper is the eccentric-wing flutter stabilizer. These lateral wings, running parallel to the bridge deck, are rigidly attached and, when positioned correctly, serve as passive aerodynamic devices that increase the flutter speed. The effectiveness of these stabilizers is heightened with greater wing eccentricity, as it enhances the aerodynamic damping of the bridge deck's rotational motion. Wind tunnel tests and analyses have corroborated these findings, suggesting that eccentric-wing flutter stabilizers can also be adapted for other structural stability applications. For the conceptual design of these stabilizers, the paper presents a parametric analytical study that explores various wing configurations and bridge systems. While this study predominantly focuses on flutter, it overlooks other effects to simplify the analysis. The computational tools developed for this parametric study are introduced within the paper.

The paper underscores the significance of considering wing length in flutter analysis. When the wing length differs from that of the bridge, it impacts the flutter mode shape. To accurately account for this, the paper introduces a multi-degree-of-freedom (MDOF) analysis method. This approach extends an established finite element flutter analysis method to incorporate the wings. Additionally, a simplified two-degree-of freedom (2-DOF) flutter analysis method is discussed, approximating wind forces on the wings under quasi-steady flow assumptions.

In conclusion, this paper offers valuable insights into flutter analysis for long-span bridges, with a specific focus on the potential advantages of eccentric-wing flutter stabilizers. It presents analytical methods, including MDOF and 2-DOF approaches, to address flutter concerns when dealing with wings of varying lengths. These insights and methodologies provide practical tools for engineers and designers engaged in the design and analysis of longspan bridges, enhancing the understanding and mitigation of flutter-induced risks. (2)

Cable-supported bridges, including suspension and cable-stayed bridges, have a rich history spanning more than two centuries. The first notable steel suspension bridge, with a 21-meter span, was constructed over Jacob's Creek in 1801, as documented by Jurado et al. in 2011. Additionally, the first cable-supported bridge made from drawn iron wires was built in Geneva in 1823. Gimsing and Georgakis (2011), Myerscough (2013), and Haifan (2011) have extensively chronicled the evolution and historical progression of long-span cable-supported bridges worldwide, starting from the early 19th century.

Flutter analysis, especially for systems with multiple modes, is commonly conducted in the modal space. Agar (1989, 1991) developed analytical methods for this purpose, employing techniques such as generalized coordinate transformations and modal superposition, as discussed by Hoa (2006, 2008).

Several researchers, including Scanlan (1978a, 1978b), Agar (1989), Jain et al. (1996b), Katsuchi et al. (1998), Gu et al. (1999), Ge et

al. (2000), and Vu et al. (2011), have adopted multi-mode approaches to study the flutter response of long-span bridges. Additionally, Ge and Tanaka (2000a), Ding et al. (2002), and Hua and Chen (2008) have examined full-order methods and compared the results with the two-mode and multi-mode procedures. In the multi-mode approach, specific modes are selected for inclusion in the analysis, while the full-order method considers all degrees of freedom (DOF), offering methodological accuracy in flutter analysis but requiring more computational time.

Chen and Kareem (2003b, 2003c, 2004, 2006a, 2006b, 2008) have contributed valuable insights into multi-mode coupled flutter. They introduced closed-form expressions for estimating modal characteristics of bridge systems and 2D flutter prediction, eliminating the need for Ceva's theorem. They also guided on selecting critical structural modes and enhancing our understanding of the multi-mode coupled bridge flutter response., The study focuses on the analysis of flutter modes using fundamental modes, particularly the torsional mode (T0 or T180) and heaving mode (H90 or H90). For thin plates, the self-excited term highlights the significant roles played by the T0 mode in torsional flutter (TB) and the H90 mode in heaving flutter (HB). During the onset of TB, the T0 mode emerges as the essential contributor, while the H90 mode tends to facilitate branch switching. This analvsis also leads to the formulation of a formula resembling Selberg's formula, based on TB characteristics during flutter onset. Additionally, the research introduces three distinct torsional divergence velocities through the use of SBSA (likely a flutter analysis technique). The study of the coupled flutter of a scale model of the Akashi-Strait Bridge reveals that it can be characterized by conventional aerodynamic 2DOF coupling (Z; f) and structural coupling between horizontal displacement and torsional motion. The simplified analytical model developed within this research effectively explains flutter characteristics observed in wind tunnel tests. The authors acknowledge that the coupled flutter in plate-like structures, including truss-stiffened bridge girders and flat box bridge girders, is predominantly characterized by 2DOF coupling (Z; f). However, they note that specific sections where aerodynamic derivatives associated with horizontal motion

exceed those associated with heaving and torsional motion may exhibit 3DOF coupled flutter phenomena (3).

This research aimed to establish a benchmark for evaluating the accuracy of Computational Fluid Dynamics (CFD) simulations in predicting flutter derivatives for various bridge deck sections. Experimental data for flutter derivatives were collected from nine different bridge deck sections through water tunnel experiments, providing a reference dataset. The study extended its scope by subjecting over 30 sections to numerical analysis using commercially available CFD software based on the Finite Volume method. The primary focus was on assessing the precision of the CFD code in predicting flutter derivatives. Encouragingly, the results demonstrated a strong agreement between the experimental, numerical, and analytical solutions in specific cases, particularly for streamlined closed sections. This implies that CFD simulations can be a reliable tool for evaluating flutter behaviours in bridge deck designs, especially for streamlined configurations. Moreover, the research delved into additional aspects, including the effective angle of attack, noncritical vibrations, and the influence of lateral motion on flutter characteristics. These investigations provided a more comprehensive understanding of bridge deck flutter phenomena. Importantly, all the experimental and numerical results are available online, serving as a valuable resource for researchers and engineers. This comprehensive dataset functions as a robust benchmarking tool, facilitating the assessment of CFD code accuracy and reliability for predicting flutter behaviour in diverse bridge deck scenarios. Ultimately, this research contributes to enhanced decision-making and improved engineering practices in the realm of bridge design and construction, promoting the safety and performance of long-span bridges in transportation infrastructure (4).

Flutter analyses, bolstered by wind tunnel tests, have underscored the potential of the eccentric-wing flutter stabilizer as a promising tool for enhancing bridge flutter stability. This innovative solution shows a notable capacity to increase bridge flutter speed, particularly in the context of long-span bridges. An important discovery is that the flutter speed increases disproportionately with the lateral eccentricity of the wings. This effect is attributed to the aerodynamic damping

that affects the angular motion of the bridge deck. Importantly, this heightened flutter speed comes at a relatively minor additional cost, making the eccentric-wing flutter stabilizer a cost-effective choice. The cost estimation for implementing this device mainly relies on the design of the wings and their supporting structures. In a representative bridge and wing configuration, the study observed a minimum 22% enhancement in flutter speed, with only a 2.5% increase in cost. Moreover, it's noteworthy that even greater improvements in flutter speed can be attained with corresponding designs, such as stacking wings vertically, without a proportional rise in expenses. Significantly, this cost-effective approach extends beyond super long-span bridges to also benefit bridges with smaller spans, approximately 200 meters or more. Such bridges, usually designed with streamlined box girder decks for wind load reduction and flutter stability, can optimize their designs and potentially transition to more cost-efficient cross-sections like open plate girder sections. Simultaneously, this solution addresses various wind-induced vibrations, not limited to flutter. In essence, the eccentric-wing flutter stabilizer offers an efficient and versatile means of boosting bridge stability and minimizing construction costs, promising improved performance across a wide range of bridge projects (5).

This paper introduces a finite element-based method that utilizes consistent self-excited aerodynamic force formulations, incorporating eighteen flutter derivatives represented in complex notation. The primary objective is to enable coupled flutter analysis for long-span bridges, and its effectiveness and accuracy are demonstrated through numerical examples. Comparisons are made between the flutter onset predictions generated by the proposed method and those obtained from existing approaches or wind tunnel tests. The results underscore the effectiveness and reliability of the presented approach. The study also explores the coupled flutter problem in the context of an asymmetric bridge, considering the full set of flutter derivatives. Numerical analyses reveal that two fundamental modes, namely the first symmetric lateral and torsional modes, play pivotal roles in initiating bridge flutter. It is noted that multi-mode analyses focused on symmetrical modes can accurately predict flutter onset. In contrast, the traditional combination of the first symmetric vertical bending and symmetric torsion modes commonly used in bimodal coupled flutter analysis proves inadequate for predicting flutter onset in the case of this asymmetric bridge. Importantly, the consistent self-excited aerodynamic force formulations yield flutter velocities that closely align with experimental results obtained from a full-bridge model in a wind tunnel, emphasizing the practical utility of this approach for engineering applications (6).

A wealth of experimental evidence has firmly established that the Strouhal number (St) with a value of approximately 0.16 holds broader significance and applicability in wind turbine engineering than initially suggested by Roshko [2]. This study further confirms the versatility of the St number in wind turbine applications, presenting a range of confirmations across various wind turbine types, including Horizontal-Axis Wind Turbines (HAWT), lift-driven Vertical-Axis Wind Turbines (VAWT), and drag-driven VAWT. While it may be tempting to assert the existence of a universal St law with St  $\approx 0.16$ capable of describing periodic fluid flow comprehensively, it is important to acknowledge that this is not entirely accurate. Several unaccounted factors, such as viscous effects, dimensionality, length and velocity scales, and free surface and blockage effects, challenge the notion of a single universal St number. Nevertheless, this study demonstrates that numerous periodic flows can be reasonably described by St numbers within a relatively narrow range centered around 0.16.

# 3. Simulation Details

Various analytical methods for determining the flutter speed of bridges equipped with stationary wings to mitigate flutter. These methods include the following: Quasi-Steady Flow Method: This approach is mentioned in the article and is likely to be used for preliminary assessments. This simplifies the aerodynamic analysis by assuming quasi-steady flow conditions, which can be suitable for initial approximations or early design stages.

Finite Aeroelastic Beam Element Method: This method involves modelling the bridge as a finite beam element with aeroelastic properties. It offers a more detailed and accurate analysis by accounting for the structural and aerodynamic interactions in the behaviour of the bridge under wind-induced forces.

Multi-degree-of-freedom (MDOF) Flutter Analysis Method: This technique can be employed for bridges with multiple degrees of freedom, considering the dynamic response of the structure to wind forces in a comprehensive manner. It takes into account Various modes of vibration and their interactions are considered. However, this article emphasizes that the most advanced and sophisticated method among those discussed is the two-degree-of-freedom (2-DOF) Flutter Analysis Method. This method is particularly notable because it incorporates the coupling between the two key degrees of freedom of the bridge deck. Translational degrees of freedom (Vertical Heave): This accounts for the vertical motion (heave) of the bridge deck. Rotational degree-of-freedom (torsion): This considers the rotational motion of the bridge deck.

The significance of this 2-DOF method lies in its ability to capture and analysed the interaction between these translational and rotational degrees of freedom. In other words, wind-induced forces not only cause vertical motion (heave) but also induce torsional motion. This coupling effect is crucial for providing a more detailed and accurate assessment of the flutter behaviours of the bridge. By considering both translational and rotational responses, the 2-DOF method provides a more comprehensive understanding of how a bridge reacts to wind-induced forces and helps engineers make informed design decisions to ensure stability and safety against flutter. The article proposes that during the initial conceptual design phase of an exceptionally long-span bridge, it can be a pragmatic strategy to give primary attention to the assessment of flutter while deferring the analysis of other wind-related effects to later stages of design.

The unique aspect of the eccentric-wing flutter stabilizer, in contrast to previous devices, lies in its fixed-wing configuration, in which the wings remain stationary relative to the bridge deck. Moreover, these wings are strategically positioned at a greater lateral distance from the bridge deck, creating substantial lateral eccentricity. This design choice is instrumental in enabling the wings to generate sufficient aerodynamic damping, thereby effectively elevating the flutter speed.

Furthermore, this study includes a thorough parametric flutter analysis that explores variations in both the properties of the bridge and wing configurations. This also provides a practical approach for selecting an economically efficient wing configuration. The study is grounded in classical bridge flutter theory and investigates steady-state harmonic vibration in the frequency domain. It assumes non-turbulent oncoming wind conditions. One notable finding is that the inclusion of wings, as reported by Meyer in 2018, reduces the bridge's response to buffeting and vortex shedding. This reduction is attributed to the aerodynamic damping generated by the wings.

The study models motion-induced lift forces and aerodynamic moments as linearly related to vertical displacements, rotations, velocities, and accelerations. This relationship is governed by analytical non-stationary aerodynamic coefficient functions, as established by Theodorsen in 1934. The study assumes that both the bridge deck and wings have aerodynamic streamlined contours. It also simplifies the analysis by neglecting aerodynamic interference between the windward and leeward wings and the bridge deck, provided the wings are positioned with sufficient vertical offset from the deck and between each other.

To ensure generality, the study presents input data and results in non-dimensional quantities. Concerning the structural properties of the bridge, the non-dimensional flutter speed depends on four non-dimensional parameters. These parameters are chosen within a space that aligns with the characteristics of existing or planned longspan bridges. Similarly, the configuration of the wings is summarized using four non-dimensional parameters, assuming identical wings on both sides of the bridge deck, as is the focus here.

The analyses are conducted using a simplified generic system—a simply supported girder with or without wings and torsional fixed ends. This system can be mapped to actual bridge and bridge-wing systems using generalization, taking into account the non-dimensional input parameters defined. A specially developed finite aeroelastic beam element is employed to model the various girder and girder-wing systems simultaneously. This approach allows for the proper consideration of wing length, which may be smaller than the bridge length. The analyses include multi-degree-of-freedom flutter analyses, and the results are presented as the flutter speed increase ratio. This ratio represents the relative increase in flutter speed attributable to the presence of wings.

# 4. Conclusion

In conclusion, the use of eccentrically attached wings to bridge decks is an effective method for enhancing flutter resistance. The findings from this study provide valuable insights into the parameters that influence flutter resistance and the cost-efficiency of this approach.

The influence of wing configuration, including eccentricity, width, and length, is significant, with over-proportional effects on flutter speed. Aesthetic concerns can be addressed by opting for more moderate eccentricity in wing design.

However, it's important to consider that in some cases, flutter resistance enhancement may not fully utilize the maximum possible flutter speed increase due to the dominance of torsional divergence. In such situations, adjusting the wing parameters is suggested to match the flutter speed increase with the divergence speed.

Overall, the study highlights the potential of eccentric wings as a cost-effective means of raising flutter resistance in bridges, and it provides a strategic framework for selecting the appropriate wing parameters to achieve the required flutter speed.

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# 15. Transformation of heavy metals and Amelioration of sodic and saline soils on Wetland Paddy Fields: A review

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#### Abstract

Azolla and blue-green algae (BGA) have a longstanding track record of enriching nitrogen levels in paddy crops. Additionally, these organisms exert influence over the physico-chemical, as well as biological attributes of soil and the soil-water interface within paddy fields, both directly and indirectly. For instance, during their growth phases, BGA releases oxygen through photosynthesis and extrudes organic molecules into the environment. Conversely, Azolla aids in weed suppression, reduces water temperature, mitigates NH3 volatilization, and regulates pH levels. The presence of Azolla and BGA contributes biomass to the soil, and upon decomposition, they affect redox processes and foster the formation of diverse organic acids. These modifications induced by Azolla and BGA in the soil could impact plant nutrient availability and overall soil properties. The objective of this review is to shed light on these influences within paddy fields and to examine potential implications for paddy-field productivity and management.

Keywords: Azolla, Blue-Green Algae, Paddy.

# 1. Introduction

Nitrogen (N) stands out as the most crucial among essential nutrients for successful paddy cultivation in tropical and subtropical regions. Efficient and cost-effective delivery of nitrogen is paramount. However, due to various chemical and biological processes, lowland paddy cultivation often experiences low nitrogen utilization efficiency from fertilizer sources. Moreover, escalating the use of nitrogenous fertilizers is deemed economically and environmentally unviable. Hence, exploring substitute renewable sources to meet some of the nitrogen requirements for paddy crops becomes imperative.

Azolla, cyanobacteria and nitrogen-fixing blue-green algae (BGA), play vital roles in sustaining and augmenting paddy crop productivity. Flooded conditions in paddy fields maintain soil nitrogen fertility more effectively than dryland conditions, facilitating favorable conditions for biological nitrogen fixation by BGA, thus ensuring steadier paddy yields. Unlike chemical nitrogen fertilizers, Azolla and BGA do not harm the environment or diminish the amount of photosynthates in paddy plants.

China and Vietnam have long utilized Azolla as a fertilizer in paddy fields due to its well-documented benefits. The establishment of nitrogen-fixing Azolla and BGA significantly enhances plant-available nitrogen in paddy soils. Noteworthy research has been conducted on both Azolla and BGA, demonstrating their agronomic significance by altering the physico-chemical, and biological characteristics of soil and the soil-water interface in paddy fields.

Field inoculation with BGA, even with 100 to 150 kg N/ha of fertilizer, has been shown to increase paddy yield by 5% to 25%, suggesting potential advantages beyond nitrogen supplementation. Azolla and BGA bring about critical physical-biochemical changes in soils through

the release of extracellular organic molecules by algae, oxygen production during active growth, and subsequent biomass addition post their decomposition. Additional benefits include preventing pH elevation, lowering water temperature, suppressing NH3 volatilization losses, and weed control under Azolla cover.

The aim of this review is to analyze and compile the limited data on the use of Azolla and BGA, exploring their potential effects on paddy growth and the long-term productivity of paddy fields.

### 2. Transformation of Heavy Metals

As mentioned previously, blue-green algae (BGA) emit oxygen (O2) and various organic compounds, as extracellular products during their growth. These compounds, as documented in studies by Watanabe (1951), El-Essawy et al. (1985), and Kerby et al. (1989), have the capacity to form chelates with micronutrients such as manganese (Mn), iron (Fe), copper (Cu), zinc (Zn), among others (Mandal et al., 1992b). Furthermore, BGA induce diurnal fluctuations in floodwater and soil pH, utilizing dissolved carbon dioxide (CO2) for photosynthesis during the day and releasing CO2 through respiration at night (Fillery et al., 1985; Roger, 1996).

In paddy soils, the anaerobic breakdown of algal biomass after their life cycle is over produces a variety of organic acids that lower soil Eh values (Saha et al., 1982). It is anticipated that these changes would impact how micronutrients are transformed and made available in soil, especially redox elements like iron and manganese. Research has shown that BGA growth causes notable reductions in the water-soluble and exchangeable Mn and Fe levels in soils, along with increases in their greater oxides (bound forms) (Saha and Mandal, 1979; Das et al., 1991). Nevertheless, this transition is reversed by the algal biomass's subsequent in situ breakdown.

The presence of BGA increases the concentration of O2 in floodwater and the related soil environment, thereby inhibiting greatly reduced conditions and slowing down the conversion of Mn and Fe from their greater-valent to lower-valent forms. Additionally, the boosting redox activity, facilitating the reduction of Fe3c and Mn4c, and decomposition of algal biomass releases electrons compounds to more soluble forms. By satisfying their higher Fe requirement during the maximal vegetative development stages, these variations in Mn and Fe concentration during BGA growth and the ensuing biomass decomposition may lessen Fe toxicity to young rice plants in acid soils rich in organic matter (Das et al., 1991).

Moreover, incorporating Azolla as green manure (GM) also affects the availability and transformation of Cu, Zn, Mn, Fe etc., in flooded paddy soils. Studies by Mandal et al. (1997) and Nagarajah et al. (1989) have demonstrated an increase in the concentration of native Mn and Fe but a decrease in that of Cu and Zn in soil solution when Azolla is used as GM. The recovery of fertilizer Cu and Zn in DTPA-extractable forms decreases initially in flooded laterite soils with Azolla as GM, but this decrease diminishes over time. However, the decrease persists longer and is more pronounced with Azolla compared to Sesbania treatment, attributed to Azolla's greater lignin content, which decomposes slowly (Mandal et al., 1997).

Additionally, Johal (1986) reported that paddy plants respond better to micronutrients (Co, Cu, Zn, Mn and Fe) supplied through Azolla compared to mineral salts providing the similr concentrations of micronutrients, which were found to be toxic to the paddy crop. These observations underscore the intricate interplay between BGA, Azolla, and soil micronutrient dynamics, with potential implications for paddy crop productivity and management.

# 3. Amelioration of Sodic and Saline Soils

Sodic and saline soils encompass a significant portion of agricultural land worldwide. Furthermore, a considerable portion of prime agricultural land annually undergoes salinization due to inadequate management and irrigation practices (Richards, 1995). Sodic soils exhibit high pH levels, elevated exchangeable sodium content, measurable carbonate levels, and extensive clay dispersion, resulting in reduced soil aeration and poor hydraulic conductivity. In contrast, saline soils contain excessive soluble salts, leading to heightened osmotic tension around plant roots, hindering water and nutrient absorption.

The recovery of sodic soils primarily involves replacing exchangeable sodium with calcium.

This is typically achieved through the application of suitable soil amendments, such as gypsum, subsequently leaching. Conversely, improving saline soils requires leaching excess soluble salts from the rhizosphere using high-quality water. Reports exist on the biological reclamation of these soils through the use of blue-green algae (BGA) (Kaushik, 1989), possibly based on observations of extensive BGA growth on salted soils in the USSR and alkali soils in India. These observations underscore BGA's considerable tolerance to alkalinity and/or salinity stress.

Several physiological mechanisms underlying BGA's tolerance to salinity and sodicity stress have been identified, including curtailing sodium influx and accumulating osmoregulators such as inorganic ions (K+ ions) or organic compounds like polyols, sugars, and quaternary amines. BGA exposed to these stresses conditions may experience diminished nitrogenase activity due to energy diversion towards osmoregulator biosynthesis. However, supplementation with a small amount of nitrogen, particularly as NO3, per hectare, along with algal inoculation, has been shown to effectively protect BGA from these stresses and enhance their potential as nitrogen biofertilizers.

Once established and acclimatized to stress, BGA may ameliorate their surrounding environment. Observations indicate significant improvements in soil properties of saline-alkali soils after algal growth, including increases in organic matter content, total nitrogen, water-holding capacity, exchangeable calcium, decreases in soil pH and various forms of phosphorus. BGA inoculation has also been associated with reductions in soil salinity and improvements in paddy yield, even under saline irrigation conditions.

However, some studies have questioned the effectiveness of BGA in reclaiming alkali soils, citing negligible changes in essential parameters such as hydraulic conductivity, pH, and exchangeable sodium content. Nevertheless, BGA's tolerance to high alkalinity and its ability to secrete organic acids and bioflocculants may temporarily mitigate sodium activity in alkali soils, creating a conducive environment for plant growth.

While biological soil enhancement with BGA is time-consuming, it is considered a sustainable approach compared to chemical modifications.

Future research may focus on improving reclamation techniques by integrating BGA application with gypsum supplementation and selecting suitable BGA species tolerant to alkalinity and salinity. Moreover, the use of genetically engineered BGA species tailored for high salinity or alkalinity environments holds promise for sustainable soil reclamation practices. Detailed feasibility studies using engineered species could pave the way for developing low-cost and sustainable technologies for sodic and saline soil amelioration.

# 4. Conclusion

Azolla and blue-green algae (BGA) are important components of paddy fields that greatly increase crop output. The electro-chemical, physico-chemical, and biological characteristics of soils and the soil-water interface in paddy fields are significantly altered in addition to the addition of nitrogen, which benefits the paddy crop in a number of ways. Organic carbon is added, soil physical properties are improved, NH3 volatilization loss is reduced, fixed phosphates are mobilized, micronutrient availability is regulated (particularly for Fe, Mn, and Zn), sodicity in problematic soils is mitigated, weeds are suppressed, and substances that promote growth are released. Occasionally, these advantages outweigh those that result from the nitrogen they add alone. But in order to fully benefit from these advantages, Azolla and BGA must grow vigorously in paddy fields, which may not always happen spontaneously. Thus, to optimize the benefits of these beneficial organisms in paddy fields, azolliculture/ algalization operations must be intensified.

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# 16. Static compaction for sustainable geotechnical solutions: A comprehensive study

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#### Abstract

The objective of the present work is to develop an improved uniaxial static compaction method to address the limitations of the traditional Proctor's dynamic approach for soil compaction. This novel approach provides several benefits, including reduced labor, enhanced soil density, and increased compactness. The study involves a comparison of static soil compaction characteristics with various soil parameters and explores the concept of equivalent static compaction energy. A diverse range of fine-grained soils with varying plasticity levels was investigated, and A notable correlation has been identified at the optimal compaction level, linking static maximum dry unit weight, peak saturation level, static compaction energy, plastic limit, and void ratio. The research resulted in the creation of constant-energy curves for static compaction, which were compared to dynamic compaction curves from four compaction attempts. The findings indicated that there is no equivalent static compaction energy corresponding to the maximum dry unit weight of dynamically compacted soil. However, the research is constrained by its focus on specific soil types, a limited sample size, and the utilization of controlled laboratory settings. Future research should encompass a wider array of soil types, explore alternative dynamic compaction techniques, conduct long-term performance assessments, investigate soil additives, employ advanced testing methods, and undertake microstructural analyses to advance the field. By addressing these constraints and considerations, this project aims to establish more reliable compaction standards and enhance our understanding of soil behavior in geotechnical engineering applications.

Keywords: Static compaction; Dynamic compaction; Static Compaction energy; Maximum dry unit weight, statistical analysis

# 1. Introduction

In geotechnical engineering, less permeable clayey soil is commonly used for building pavements, highways, railway embankments, and containment barriers. Compaction is a technique used to improve the geotechnical properties of soil by increasing its density and altering its structure. The strength and usefulness of a well-compacted subgrade depends on its physical properties, which can be tested using the dynamic compaction test originally proposed by Ralph Roscoe Proctor (Proctor 1945). The Standard Proctor Test ASTM D698-91(2012) and Modified Proctor Test ASTM D1557-91(2012) are commonly used methods for soil compaction based on the requirements of the field and structure.

Proctor discovered that each soil has an optimal moisture content at which it can achieve maximum density, and that stability decreases as the moisture content rises above this point, but increases as it falls below it. However, soil compacted below the optimal moisture content can only retain its higher stability if it does not get wet. In 1937, (Hogentogleb, n.d.) made an observation that compressed soil samples undergo four distinct stages of wetting before reaching complete saturation with water. These stages are hydration, lubrication, swelling, and saturation.

Throughout the compaction process, the energy applied to the soil significantly influences properties such as shear strength, permeability, and swelling pressure. Research indicates that raising the compaction energy can enhance the shear strength of cohesive soil, particularly when compacted on the dry side of the compaction curve. Dynamic compaction has been the traditional method, but Reddy et al. pointed out significant drawbacks in the test (Venkatarama Reddy and Jagadish 1993). They found that the soil compaction parameters such as optimum moisture content (OMC) and maximum dry unit weight (MDUW) determined by the dynamic Proctor test, are subjected to the applied energy input and the quality of compaction energy given to specific soil types. To tackle these challenges, Reddy et al. devised a novel laboratory static compaction method that facilitates easy variation of energy input (Venkatarama Reddy and Jagadish 1993). Other researchers, such as A. Mesbah have et al. redesigned the testing mould to regulate boundary friction (Mesbah, Morel, and Olivier 1999). The gap between predicted compaction properties in the laboratory and desirable properties in the field is highlighted by M. A. Hafez et al. (Hafez, Doris Asmani, and Nurbaya 2010). They discovered that the static pressure curve bears a resemblance to the Proctor curve for fine-grained soil. Static compaction is widely regarded as a more convenient, straightforward, and time-efficient method in comparison to dynamic compaction. R. K. Bernhard et al. have also compared the effectiveness and efficiency of static and dynamic compaction techniques (Bernhard and Krynine 1952). For studying fine-grained soil compaction behavior, A. Sridharan et. al. proposed a new laboratory approach that requires only about 1/10th of the volume of soil needed for the standard and Proctor test (Asuri Sridharan and Sivapullaiah 2005). Additionally, studies have been conducted to forecast soil compaction characteristics based on soil index properties by (A. Sridharan and Nagaraj 2004) and (A. Sridharan and Nagaraj 2005).

Several research studies have investigated the effects of laboratory static compaction on soil properties. B. Sharma et. al. found that increasing static pressure led to significant increases in dry unit weight, but the variation became negligible at higher pressure levels (B. Sharma, Sridharan, and Talukdar 2016). They also identified an equivalent static compaction pressure that correlated with the energy input required to achieve MDUW in standard Proctor tests. B. Sharma et. al. expanded on this work by studying multiple soil types and determining the equivalent static compaction pressures needed to achieve MDUW in reduced standard Proctor and reduced modified Proctor tests (Binu Sharma and Deka 2019). L. Xu et al. investigated the relationship between soil compaction and saturation degree, introducing the concept of optimum saturation degree to represent the degree of saturation corresponding to MDUW and OMC (Xu et al. 2021) . Additionally, they observed that specimens undergoing static compaction tests exhibited slightly higher matric suction compared to those subjected to dynamic Proctor tests at the same moisture content. F. A. Crispim et al. examined the impact of static and dynamic laboratory compaction procedures on compaction curves and mechanical strength in two soil types, and found that soil structure plays a significant role in compaction and mechanical properties (Crispim et al. 2011). K. Kayabali et. al. conducted a comparison of undrained shear strength and hydraulic conductivity of soil under static and dynamic compaction methods (Kayabali et al. 2020).

The current work aims to devise a modified uniaxial static compaction technique that is capable of producing a series of static compaction curves, also referred to as constant-energy curves. The study involves analyzing test result data and conducting a statistical analysis to propose general prediction equations for MDUW and OMC of statically compacted soil. These prediction equations correlate with other soil indices, such as peak saturation level (Sp), input static compaction energy (Es) at optimum compactness, plastic limit (Wp), and plasticity index (PI). The study also investigates the existence of an equivalent static compaction energy (Es,eq) corresponding to the MDUW achieved at different dynamic compaction efforts for fine-grained soils with varying plasticity characteristics. Additionally, the study analyzes the behavioral pattern of static compaction.

#### 2. Soil Compaction Test

#### 2.1 Dynamic Compaction of Soil

The Proctor test, or dynamic compaction test, is a soil compaction method that involves applying a specific amount of energy. It utilizes a standard mould filled with moist soil, which is compacted by striking the topsoil with a standard hammer. Two levels of compaction are used: standard Proctor and modified Proctor, with different compaction energies (592.5 KJ/m<sup>3</sup> and 2703.88 KJ/m<sup>3</sup>, respectively). The compaction energy can be adjusted by changing the hammer weight, drop height, blows per layer, and compacted layers.

The compaction energy per unit volume can be calculated using the following equation:

#### $E = (N \times n \times W \times H) / V$

Where, N = blowcount/layer of soil, n = number of soil layer, H = free fall of the standard rammer, H = height of the filled soil and V = total volume of the compacted soil. This study examined four levels of compaction energy: standard Proctor (Es =  $592.5 \text{ KJ/m}^3$ ), modified Proctor (Em =  $2703.88 \text{ KJ/m}^3$ ), reduced standard Proctor (Ers =  $355.5 \text{ KJ/m}^3$ ), and reduced modified Proctor (Erm =  $1622.33 \text{ KJ/m}^3$ ).

#### 2.2 Static Compaction of Soil

The static compaction test was conducted using a mould similar to the Proctor mold, featuring a diameter of 10 cm and a height of 12.7 cm, with a modification. Previous studies have suggested that the thickness of the test sample does not have a significant impact on its dry unit weigh [10]. Therefore, the soil was filled into the mould with an initial sample height of 106 mm. To minimize the effect of wall friction during the compaction process, silicon grease was added to the inner wall of the mould. The test setup was then placed in the loading frame under a cylindrical plunger with a diameter of 50 mm, and the soil sample was compacted statically at a rate of 1.25 mm/min. The load was applied through a proving ring with a proving ring constant of 0.99 kg/div. In order to evenly distribute the applied static load across the entire depth of the soil within the mold, two surcharge plates were positioned at the top of the soil mass inside the mould. These plates had diameters of 99.50 mm and thicknesses of 6 mm and 15 mm, respectively.

The rigid plunger exerts a static load on the metal plate positioned atop the soil sample, resulting in uniform settlement of both the plates and the soil. Throughout the compaction process, meticulous attention was given to ensuring smooth plunger movement. The penetration height of the metal plate and the compressed soil from the top surface were carefully measured, corresponding to the different applied static loads.

The static compaction technique used in the present work follows the constant peak stress-variable stroke approach. The application of static load persisted until the compressed height of the soil within the mould reached a steady state or the penetration of the metal plate ceased. Given the known moisture content of each soil sample, the corresponding dry unit weight was calculated.

From the result outcomes of the static compaction tests for a specific soil type, constant-energy curves were identified, considering identical compaction energy. For each load increment, static pressure (P), compaction energy (E), void ratio (e), and degree of saturation (S) were determined. The objective of this study is to create an extensive dataset for future use in regression analysis.

### 3. Materials

Seventeen different fine-grained soils with varying plasticity properties were selected for experimentation purposes. The physical characteristics of each soil sample were measured according to the recommendations of the Bureau of Indian Standards (BIS) and the results are shown in Table 1. The MDUW and corresponding OMC for each soil sample were determined under different levels of energy input, following the guidelines provided in IS:2720-7 (1980) and IS:2720-8 (1983). Total 4 classes of fine grained soil are selected for the present study: CH (33.60 < PI < 58.52), CI (21.89 < PI < 30.58), CL (12.64 < PI < 25.65) and ML (5.34 < PI < 10.20).

Table 1 provides a list of abbreviations utilized in the study, including: SPMDUW for Std. Proctor's Max. Dry Unit Weight, SPOMC for Std. Proctor's Optimum Moisture Content, MPMDUW for Modified Proctor's Max. Dry Unit Weight, MPOMC for Modified Proctor's Optimum Moisture Content, RSPMDUW for Reduced Std. Proctor's Max. Dry Unit Weight, RSPOMC for Reduced Std. Proctor's Optimum Moisture Content, RMPMDUW for Reduced Modified Proctor's Max. Dry Unit Weight, and RMPOMC for Reduced Modified Proctor's Optimum Moisture Content.

# 4. Experimental Investigations Outcome

Table 1: Physical properties of targated soils

Soil No	WL (%)	Wp (%)	Gs	USCS type	SP MDUW (KN/m3)	SP OMC (%)	MP MDUW (KN/m3)	MP OMC (%)	RSP MDUW (KN/m3)	RSP OMC (%)	RMP MDUW (KN/m3)	RMP OMC (%)
1	59.11	16.86	2.55	CH	17.02	14.84	18.53	14.11	16.58	15.09	18.11	14.56
2	36.57	26.54	2.83	ML	15.73	24.00	16.81	22.78	15.12	24.57	16.23	23.36
3	36.59	31.19	2.82	ML	14.35	29.95	15.58	27.09	13.93	30.17	14.86	28.26
4	45.17	19.52	2.8	CL	17.57	17.53	18.74	16.24	17.11	17.94	18.07	16.85
5	32.13	19.49	2.65	CL	16.19	17.36	17.24	16.13	15.71	17.82	16.86	16.91
6	59.55	18.95	2.6	CH	16.91	16.87	17.87	15.58	16.29	17.04	17.33	16.12
7	27.53	22.19	2.82	ML	16.93	19.62	17.66	18.04	16.17	20.11	17.22	18.34
8	33.64	27.41	2.72	ML	14.18	25.15	15.22	24.12	14.02	25.66	14.73	24.83
9	72.21	18.93	2.75	CH	16.97	17.46	17.95	17.17	16.65	17.51	17.77	17.29
10	48.84	18.26	2.72	CI	16.42	18.57	17.51	18.39	16.13	18.63	17.32	18.49
11	45.52	19.17	2.63	CI	16.12	18.64	16.95	17.84	15.87	18.78	16.75	18.42
12	78.65	20.13	2.77	CH	16.51	18.61	17.63	18.37	16.25	18.65	17.3	18.41
13	57.42	16.33	2.65	CH	17.23	15.45	18.24	15.14	16.92	15.54	18.04	15.26
14	39.54	17.65	2.73	CI	16.72	17.59	17.88	17.36	16.47	17.65	17.72	17.44
15	30.18	23.27	2.80	ML	15.95	22.22	16.88	21.8	15.78	22.25	16.63	21.88
16	38	27.8	2.78	ML	14.51	20.35	15.64	19.17	14.15	20.81	14.97	19.74
17	65.20	31.60	2.66	CH	15.21	23.28	16.44	21.4	15.03	23.64	15.88	22.36

The study conducted static compaction tests on various soil types at different moisture levels and applied static loads. Respective values energy input, dry unit weight, void ratio, and degree of saturation were measured. Furthermore, variations of dry unit weight with moisture content at different input compaction energy levels were also obtained. The relationship between dry unit weight and moisture content for a particular soil type at a specific Es level is found to be parabolic. The typical relationship between dry unit weight and moisture content, corresponding to different input compaction energy levels for CI soil (soil no. 10), is shown in Figure 1.





In Figure 1, the static compaction curves for different compaction energy inputs are superimposed with dynamic compaction curves corresponding to four unique compaction energy inputs. Figure 1 represents a series of constant-energy curves for CI soil, where ES varies from 10.69 KJ/m<sup>3</sup> to 610.70 KJ/m<sup>3</sup>. For all soil samples tested, comparable curves were observed, and Table 2 displays the average range of Es necessary for achieving maximum compactness. It has been observed that to achieve MDUW under static compaction, the required range of ES for CH is comparatively higher due to the presence of high fine particles and plasticity. Both dynamic and static compaction curves are parabolic in nature, and they shift upward, representing higher MDUW with a rise in ES.

It has also been observed that static compaction results in a higher density than dynamic compaction at a specific compaction energy, but no static compaction curve lies above the modified Proctor curve. For all tested soil samples, an ES ranging from 160 KJ/m<sup>3</sup> to 385 KJ/ m<sup>3</sup> is required to attain SPMDUW associated with a specific energy input of 592.5 KJ/m<sup>3</sup>. Moreover, to reach RSPMDUW associated with a specific energy input of 355.5 KJ/m<sup>3</sup> in the dynamic compaction method, static compaction utilizes an energy input ranging from 160 KJ/m<sup>3</sup> to 330 KJ/m<sup>3</sup>. Therefore, it can be understood that in static compaction, when ES reaches the level of standard Proctor energy, a much higher dry unit weight of the soil can be obtained compared to the standard Proctor test. Similar findings were observed in the case of reduced standard and reduced modified Proctor compaction tests.

 Table 2: Avarege Range of Es for maximum compactness

Soil type	Es (KJ/m3)
СН	670 – 777
CI	570 - 650
CL	550 - 620
ML	530 - 600

# 5. Statictical Analysis of Static Compaction Characterictics

The static compaction curves have yielded an extensive dataset that includes MDUW, OMC and the corresponding value of ES, SP, e, and WP. All soil parameters were measured in the laboratory in accordance with BIS specifications.

Considering MDUW and OMC as dependent variables and the rest of the parameters as independent variables, this study attempted to generate two multilinear regression models. The reason behind the selection of the independent variables is that each independent variable significantly affects the static compaction.

In Figure 2, we present the variation curves of SP along with the corresponding ES values for all the tested soil samples. We observed that as ES increases, SP gradually rises until it reaches a range between 0.70 and 0.75, with the induced compaction energy ranging from 260 KJ/m<sup>3</sup> to 300 KJ/m<sup>3</sup>. However, after reaching an average compaction energy of 280 KJ/ m<sup>3</sup>, the variation curve of SP shows a decreasing slope, and its values now span between 0.70 and 0.90. Therefore, to ensure consistency and reliability in the regression model, we omitted SP values corresponding to compaction energies up to 280 KJ/m<sup>3</sup> and only used values higher than 0.70. It is worth noting that the manual filling of soil into the compaction mould might not have been entirely uniform, and this could have led to unevenly compacted soil samples. Consequently, we decided to disregard the initial test results obtained at lower static energy levels.

$$= \frac{ax}{1+Ky} - bx^{2} - \frac{(\beta + \sigma y)(1-m)xy}{1+\alpha(1-m)x}(1)$$
$$= \frac{c(\beta + \sigma y)(1-m)}{1+\alpha(1-m)x}$$
(2)

dx

dt

dx

dt



Figure 2: Variation curves of peak saturation level w.r.t. compaction energy

75% of the total dataset are used as a training dataset in the construction of the correlation models and rest of the data are used for validation of the model. The descriptive statistics of the training dataset such as means, standard deviations, minimum and maximum values, skewness, and kurtosis are presented in Table 3. The descriptive analysis of the soil data produced significant new information about each variable's features. We looked at measures like mean, standard deviation, minimum, maximum, skewness, and kurtosis for each variable in the dataset, which contained 368 observations. The findings revealed significant variances in the data, with Standard Compaction Energy (ES) displaying a broad range from 7.936 to 982.792 and a significant standard deviation of 228.8436. With standard deviations of 0.1444 and 0.2294, respectively, Peak Saturation Level (SP) and Void Ratio (e) showed comparatively less fluctuation. Both the Plastic Limit (WP) and the Optimal Moisture Content (OMC) displayed moderate variability. Unusually, Maximum Dry Unit Weight (MDUW) exhibited a distribution that appeared to be slightly left-skewed, with a relatively narrow range from 10 to 18.6684. Skewness measures the

asymmetry of the distribution, while kurtosis measures the peakedness or flatness of the distribution. Values close to zero indicate normal distribution. Overall, these descriptive statistics provided vital information on the traits and distribution of the variables in the soil dataset and formed the groundwork for additional analysis, such as the multilinear regression.

Variable	N	Minimum	Maximum	Mean	Std. Deviation	Skewness		Kurtosis	
Statistic		Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error	Statistic	Std. Error
Es	368	7.936	982.792	280.32172	228.84363	0.984	0.127	0.266	0.254
Sp	368	0.3904	0.9874	0.745384	0.1444302	-0.357	0.127	-0.857	0.254
e	368	0.4177	1.5514	0.78603	0.2294107	0.546	0.127	-0.219	0.254
Wp	368	16.36	27.47	20.9854	3.62347	0.61	0.127	-1.054	0.254
OMC	368	15.28	29.93	19.886332	4.2107737	1.113	0.127	0.257	0.254
MDUW	368	10	18.6684	15.650328	1.7022124	-0.644	0.127	-0.067	0.254

 Table 3: Descriptive Statistics

The next step is to establish the relationship equation by performing a multiple linear regression analysis. The general relationship of static compaction MDUW and OMC with ES, SP, WP and e for fine-grained soil based on multiple regression analysis are:

MDUW=14.51+9.8×Sp-0.3×Wp-1.4×e-0.001 ×Es (i)

 $OMC = -7.56 + 7.9 \times Sp + 0.814 \times Wp + 6 \times e^{-0.001 \times Es}$  (ii)

The coefficient values assigned to each factor indicate their respective contributions and directions of influence. The positive coefficient for Sp suggests that higher degrees of saturation tend to enhance MDUW, possibly due to improved particle packing. Conversely, the negative coefficients for Wp and e imply that greater plasticity and void ratios are associated with reduced MDUW. The reversal of the relationship between MDUW and ES when other independent variables are included in the model can be attributed to a phenomenon known as multicollinearity. The Variance Inflation Factor (VIF) is used to assess multicollinearity among independent variables in a regression analysis. In this case, VIF values for each independent variables are within the acceptable range between 2 to 3. The p-values associated with each coefficient, which indicate the significance of each independent variable's contribution to the model were also less than the chosen significance level (often 0.05).

Table 4 displays the fitness values for both correlations. This table provides information on R, R2, adjusted R2, and the standard error

of estimates. 'R' represents the multiple correlation coefficients, which can be considered as one of the qualitative measures for predicting the dependent variable (Field 2003). A value of 0.94 for both predicted models indicates a high level of prediction accuracy. The R2 value, or coefficient of determination, signifies the proportion of variance explained by the independent variable (Field 2003). Considering the R2 value in Table 4, it can be inferred that the independent variables explain 88% of the variability in the dependent variable MDUW and OMC. R-squared is initially intuitive and provides insight into how well a regression model fits a dataset. However, for a comprehensive understanding of the model, it's essential to consider adjusted R2 and the standard error of estimates in addition to R2. Adjusted R2 holds particular importance in data interpretation. A value of 0.88 in Table 4 indicates that a true 88% of the variation in the outcome variable is explained by the predictors that are retained in the model. Table 4 shows that the R2 values and adjusted R2 values are very close, suggesting a good fit of the data (Field 2003). The standard error, a measure of model accuracy, represents the standard deviation of the residuals. The standard error decreases with higher R2 values (Field 2003). From the standard error values, it is evident that the estimations of MDUW and OMC values with the help of ES, SP, WP, and e will deviate by 0.58 and 1.4, respectively, which can be considered negligible.

 Table 4: Regression Analysis Model Fitness Metrics

 for MDUW and OMC in Relation to ES, SP, WP,

 and e for Fine-Grained Soil

Dependent Variable	R	R Square	Adjusted R Square	Standard Error of the Estimate
MDUW	0.94	0.884	0.883	0.58
OMC	0.94	0.882	0.880	1.4

The model undergoes validation using 25% of the total dataset, and the RMSE is computed based on the actual and predicted values. In Figure 3, the actual and predicted graph for MDUW values is shown. The RMSE for the model is found to be 0.93, indicating a well-fitted model. Moreover, the MAD value came in at 0.88, suggesting acceptable variability in the dataset. This means the data is not spread out too much.



Figure 3: Actual vs. predicted MDUW (in KN/m3)

# 5. Determination of Equivalent static Compaction Energy (Es,eq)

Since there are similarities in the dynamic and static compaction curves, an equivalent static pressure (ESP) can be identified at which the MDUW for a specific dynamic compactive effort can be achieved [10] presented the equivalent static pressure required to attain the MDUW, which can also be achieved from the standard Proctor test, for specific fine-grained soils. To determine ESP concerning the SPMDUW, a set of two static compaction curves corresponding to specific static pressures has been selected in such a way that the standard Proctor's curve lies between them. Assuming a linear variation of MDUW between the selected static compaction curves, the pressure equivalent to the SPMDUW was established.

In this research, an effort has been made to identify the ESCE, which represents the precise static compaction energy required to achieve MDUW by the standard Proctor, reduced standard Proctor, and reduced modified Proctor test. From Figure 1, it is clear that there is no static compaction curve above the modified Proctor curve. Hence, achieving static energy equivalent to the MDUW obtained from the modified Proctor test is not feasible.

The ESCE values for standard Proctor, reduced standard Proctor, and reduced modified Proctor tests on CH soil (soil no. 13) were determined as 270, 235, and 532 KJ/m3, respectively. A similar approach was employed to ascertain the ESCE required to achieve MDUW using the three dynamic compactive efforts across various soil samples with different plastic characteristics. It was revealed during the investigation that, unlike equivalent static pressure, fine-grained soil lacks a unique ESCE value.

The average ESCE ranges for standard Proctor, reduced standard Proctor, and reduced modified Proctor tests on all tested soil samples were found to be 180-340, 155-308, and 532-664 KJ/m3, respectively. When examining specific soil types, the equivalent static energies, based on the standard Proctor effort, fall with-in the following ranges: 245-270 KJ/m<sup>3</sup> for CH soil, 180-280 KJ/m<sup>3</sup> for CI soil, 280-340 KJ/m<sup>3</sup> for ML soil, and 205-310 KJ/m<sup>3</sup> for MI soil.

The variation in Equivalent Static Compaction Energy (ESCE) values occurs because the input energy is contingent upon the deformation of the compacted soil. Static compaction energy is influenced by soil properties such as particle size and shape. Among rounded and angular particles, angular particles exhibit a stronger interlocking phenomenon. This implies that, under the same static compaction energy, angular particles will experience more compaction compared to rounded particles. Consequently, achieving the desired compaction level requires more static compaction energy for rounded particles than for angular particles.

It has been noted that under identical static compaction energy, poorly graded soil tends to undergo greater compaction compared to well-graded soil. As a result, achieving the desired compaction necessitates more static compaction energy for well-graded soil compared to poorly graded soil. Hence, the concept of equivalent static energy cannot be established definitively. Since static compaction energy is influenced by soil properties, the equivalent static energy is not constant, leading to the absence of an equivalent static energy value for fine-grained soil.

# 6. Behaviour Characteristics of Static Compaction Curves

The experimental results of the static compaction test, including static compaction energy, degree of saturation, and dry unit weight for certain fine-grained soils, are depicted graphically. The relationship between dry unit weight and static compaction energy input corresponding to CL soil is shown in Figure 4. When examining these graphs, it becomes evident that, for specific soil types and at any moisture content, an escalation in compaction energy results in an increase in dry unit weight until the maximum value is attained. Nevertheless, once the maximum compactness value is reached, there is no further alteration in dry unit weight despite an increase in compaction energy. Similar findings have been observed in other soil samples.



Figure 4: Variation of Compaction energy with dry unit weight of soil.

The variation in the degree of saturation with static energy is presented in Figure 5. The degree of saturation increases gradually with increase in the c energy input, but once MDUW is attained, it remains constant. Moreover, considering four different moisture contents, curves of the degree of saturation and compaction energy as a function of dry unit weight have been prepared (Figure 6). The graph indicates a linear increase in the degree of saturation as the dry unit weight increases. By comparing the static compaction curve (for WC = 22.45%) with standard Proctor test results (MDUW = 15.95 KN/m3 and OMC = 22.22%), it was found that to achieve the same state of dry unit weight for almost near moisture content, static compaction requires less energy input. The Proctor test method necessitates extra compaction energy to counteract the loss of energy, which could stem from frame vibration or wall friction. In addition, the variation of the SP corresponding to MDUW for all tested soil samples is shown in Figure 7. The nature of the variation curve follows the power law form, where each point in the curve represents different compaction energy.



Figure 5: Variation curve of the degree of saturation with static compaction energy unit weight of soil.



Figure 6: Variation curves of the degree of saturation and compaction energy w.r.t. DUW



Figure 7: Varitaion curves of the peak saturation levels w.r.t. MDUW

# 7. Conclusion

For the current study, a diverse range of finegrained soils with varying plasticity was chosen and compacted in the laboratory using four different dynamic compaction techniques and a constant peak stress-variable stroke static compaction approach. The static compaction curves for various compaction energy inputs were compared with dynamic compaction curves and presented as a series of constant-energy curves for each soil sample.

The comparative study of static and dynamic compaction tests showed that static compaction can result in a much higher dry unit weight than dynamic compaction at the same energy level, regardless of the compaction efforts used. Additionally, it was observed that there is no Es,eq for fine-grained soil, unlike equivalent static pressure. The average range of Es,eq for standard Proctor, reduced standard Proctor, and reduced modified Proctor for all tested soil samples was found to be 180-340, 155-308, and 532-664 KJ/m<sup>3</sup>, respectively. The state of the soil structure at the induced compaction energy and the mineralogical composition of the finegrained soil were found to be responsible for the variation of ESCE.

Furthermore, this paper investigated the influence of various soil parameters on Maximum Dry Unit Weight (MDUW) under static compaction and developed an acceptable correlation of MDUW with the corresponding peak saturation level, compaction energy, plastic limit, and plasticity index.

Additionally, from the static compaction test, it was observed that the dry unit weight of the soil seems to increase gradually with an increase in compaction energy at a specific moisture content. After reaching the maximum level of compaction, the soil unit weight remains constant with further increases in compaction energy. Finally, it was also noted that initial static compaction test results at lower energy input could be disregarded due to the non-uniformity of soil filling in the compaction mold.

Despite its limitations, future research should explore a wider variety of soil types, additional compaction techniques, long-term performance analysis, correlations with various soil parameters, advanced testing methods, soil additives, and microstructural analysis. These efforts will enhance indepth understanding and advance the field. By including these factors, compaction standards will become more reliable, and applications for geotechnical engineering will have a better grasp of soil behaviour.

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# 17. ATbot: Intelligent system for improved trading strategies under the framework of data science

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#### Abstract

In the modern era of financial markets, the integration of Artificial Intelligence has revolutionized trading strategies by augmenting decision-making processes with data-driven insights. The presented work aims to design, develop and evaluate an AI-based trading bot that leverages a multifaceted approach to stock trading by analyzing a comprehensive array of indicators, patterns, and news. The primary objective of the project is to provide traders with refined stock and index recommendations, enabling them to optimize profitability.

Any kind of trading strategy largely depend on Predictive Analytics. The long- and short term investment decisions are mostly emerging out of these predictive models almost in a deterministic frame though the real-world stock market is full of uncertainties. This predictive analytics emerges from mainly three different type of analysis viz. fundamental analysis, sentimental analysis and technical analysis.

The proposed AI trading bot, abbreviated as ATbot, capitalizes on advanced machine learning algorithms to process an extensive range of technical and fundamental indicators. Through deep analysis of historical price data, trading volumes, and fundamental ratios, the bot can identify patterns and trends that would be challenging for human traders to detect. Additionally, the incorporation of sentiment analysis of news and market reports ensures that the bot can respond dynamically to real-time events and news developments that could impact market sentiment.

The development process of the AI trading bot encompasses several key stages. Firstly, data collection involves sourcing historical price data, trading volumes, and relevant fundamental metrics for a diverse set of stocks and indices. Simultaneously, real-time news feeds are integrated to facilitate sentiment analysis. Secondly, the data undergoes thorough preprocessing to ensure accuracy and consistency. Features such as moving averages, relative strength indices, price-to earnings ratios, and other technical and fundamental indicators are computed.

Machine learning models play a pivotal role in the project's success. The bot employs a combination of supervised and unsupervised learning techniques. Supervised learning facilitates the training of predictive models that forecast price movements based on historical data and feature-rich inputs. Unsupervised learning enables the identification of hidden patterns and correlations within the data, further enhancing the bot's decision-making capabilities.

Keywords: ATbot, fundamental analysis, sentimental analysis, technical analysis, trading strategy.

### 1. Introduction

In the dynamic landscape of today's financial markets, the fusion of Artificial Intelligence has sparked a transformative wave, reshaping the very essence of trading strategies. With an unwavering focus on enhancing decision-making through data-driven insights, the groundbreaking research presented here endeavours to craft a pioneering AI-based trading companion - ATbot. Nestled within the heart of the financial world, this digital sentinel hails from the laboratories of innovation at esteemed institutions in West Bengal, India.

The mission of ATbot is nothing short of revolutionizing stock trading through a multi-faceted approach. It deftly navigates the intricate tapestry of indicators, patterns, and news, ushering in a new era where traders are empowered with refined recommendations for stocks and indices. At its core, this project revolves around the science of Predictive Analytics, which serves as the compass guiding long and short-term investment decisions in the unpredictable realm of the stock market.

This predictive prowess draws its strength from a trio of analytical pillars: fundamental analysis, sentimental analysis, and technical analysis. Through the amalgamation of advanced machine learning algorithms, ATbot unravels an extensive spectrum of technical and fundamental indicators. By meticulously sifting through historical price data, trading volumes, and fundamental ratios, it has the power to unearth patterns and trends that often elude human traders. What sets ATbot apart is its capacity to dynamically respond to real-time events and market shifts, thanks to its incorporation of sentiment analysis of news and market reports.

The journey towards creating this AI trading marvel is a multi-stage odyssey. It commences with the meticulous collection of historical price data, trading volumes, and essential fundamental metrics for a diverse portfolio of stocks and indices. Simultaneously, it harnesses the pulse of real-time news feeds, setting the stage for sentiment analysis. This influx of data is then meticulously preprocessed to ensure precision and uniformity, with computations spanning moving averages, relative strength indices, priceto-earnings ratios, and a rich tapestry of other technical and fundamental indicators.

However, the true stars of this show are the machine learning models that drive ATbot's decision-making prowess. Employing a synergistic blend of supervised and unsupervised learning techniques, this digital savant paints a vivid picture of market dynamics. Supervised learning guides the creation of predictive models, honed through historical data and feature-rich inputs, foreseeing price movements with a keen eye. In parallel, unsupervised learning delves into the hidden patterns and correlations that lay concealed within the data, further enriching ATbot's decision-making acumen.

In this realm where numbers dance to the rhythm of market sentiment, ATbot stands as a beacon of innovation. It is our privilege to introduce this remarkable creation, as it embarks on a mission to redefine trading strategy with its formidable arsenal of ATbot, fundamental analysis, sentimental analysis, technical analysis, and an unwavering commitment to the pursuit of optimized profitability. Welcome to the future of trading, where data science meets intelligent systems in a quest to reshape the world of finance.

#### 2. Literature Study

"Building Chatbots with Python: Using Natural Language Processing and Machine Learning" by Sumit Raj

**Description:** This practical guide focuses on building chatbots using Python, NLP, and ML, which can be directly applicable to developing ATBot.

"Chatbot Development with Bot Framework: Build Intelligent Bots Using MS Bot Framework and Azure Cognitive Services" by Shashangka Shekhar

**Description:** This book focuses on developing chatbots using Microsoft Bot Framework and Azure Cognitive Services, which can be useful for implementing features in ATBot.

"Deep Learning" by Goodfellow, Bengio, and Courville

**Description:** This comprehensive book covers deep learning concepts, which are essential for understanding advanced techniques used in conversational agents.

"Designing Voice User Interfaces: Principles of Conversational Experiences" by O'Flaherty and Cohen

**Description:** This book covers the principles of designing voice user interfaces, which can be valuable for creating a conversational experience with ATBot.

"Machine Learning for Dummies" by Mueller and Massaron

**Description:** This book provides a beginner-friendly introduction to machine learning, which is a key technology behind intelligent bots like ATBot.

"Natural Language Processing in Action" by Lane, Howard, and Hapke

**Description:** This book provides a practical introduction to NLP concepts and techniques, which are essential for building conversational agents like ATBot.

# 3. Methodological Aspects

#### 3.1 Chart Pattern Identification

YOLO (You Only Look Once), a popular deep learning object detection framework, to identify chart patterns in a way that appears as if you are writing:

Introduction: In the ever-evolving world of stock market trading, the ability to quickly and accurately identify chart patterns is invaluable. These patterns provide critical insights into potential price movements and are essential for making informed trading decisions. Leveraging modern technology, we can now employ advanced deep learning techniques like YOLO to automate the process of recognizing these patterns. In this methodological aspect, we will explore the steps and considerations involved in using YOLO for chart pattern identification.

Data Collection: The foundation of any successful machine learning project is high-quality data. To train YOLO to recognize chart patterns, we first need a robust dataset of historical stock charts. These charts should cover various timeframes, stocks, and market conditions. Each chart should be labeled with bounding boxes specifying the locations of chart patterns.

Data Preprocessing: Preparing the dataset is a crucial step. It involves resizing images to a standard resolution, normalizing pixel values, and converting labels into a format that YOLO can understand. Each label should include the class of the chart pattern and the coordinates of the bounding box.

Model Selection: YOLO offers several versions, each with varying levels of accuracy and speed. Choosing the appropriate YOLO model depends on factors such as available computational resources and the real-time nature of trading. YOLOv7 or YOLOv8 may be suitable choices for this task.

**Training:** Training YOLO to identify chart patterns requires a considerable amount of computational power and time. During training, the model learns to detect specific patterns by adjusting its internal parameters. It's essential to monitor the training process, check for overfitting, and fine-tune hyperparameters as needed.

Labelling Tool: To create bounding box annotations for the dataset, you may need a labelling tool that allows you to draw boxes around chart patterns in the images. This tool helps generate the ground truth data required for training YOLO.

Testing and Validation: After training, it's crucial to evaluate the model's performance on a separate validation dataset. This step helps ensure that the model can generalize well to unseen data and accurately detect chart patterns.

Integration into Trading System: Once the YOLO model is trained and validated, it can be integrated into your trading system. When analyzing real-time stock charts, the model can identify and classify chart patterns, providing you with valuable insights.

#### 3.2 Technical indicators

Moving Averages (MA): Moving Averages help smooth out price data over a specified period, providing a trend-following indicator.

Simple Moving Average (SMA) Equation:

SMA = (Sum of closing prices for 'n' periods) / 'n'

How to Use: When the current price crosses above the SMA, it may signal a bullish trend, indicating a potential buy.

When the current price crosses below the SMA, it may signal a bearish trend, indicating a potential sell.

**Relative Strength Index (RSI):** RSI measures the speed and change of price movements, helping to identify overbought or oversold conditions.

**RSI Equation:** 

RSI = 100 - (100 / (1 + RS))

RS = (Average Gain / Average Loss)

How to Use:

An RSI above 70 suggests an overbought condition, indicating a potential sell.

An RSI below 30 suggests an oversold condition, indicating a potential buy.

Moving Average Convergence Divergence (MACD): MACD combines two moving averages to provide both trend-following and momentum indicators.

MACD Line Equation:

MACD Line = Short-term EMA - Long-term EMA

How to Use: When the MACD Line crosses above the Signal Line, it may signal a bullish trend and a potential buy.

When the MACD Line crosses below the Signal Line, it may signal a bearish trend and a potential sell.

Bollinger Bands:

Bollinger Bands consist of a middle band (SMA) and two outer bands representing standard deviations of price.

**Bollinger Bands Equations:** 

Middle Band (SMA) = (Sum of closing prices for 'n' periods) / 'n'

Upper Band = Middle Band + (K \* Standard Deviation)

Lower Band = Middle Band - (K \* Standard Deviation)

How to Use: When prices touch or cross the upper band, it may signal an overbought condition, indicating a potential sell.

When prices touch or cross the lower band, it may signal an oversold condition, indicating a potential buy.

Stochastic Oscillator:

The Stochastic Oscillator measures the position of the current close relative to the price range over a specified period.

Stochastic Oscillator Equation:

%K = [(Current Close - Lowest Low) / (Highest High - Lowest Low)] \* 100

How to Use: %K above 80 suggests an overbought condition, indicating a potential sell.

%K below 20 suggests an oversold condition, indicating a potential buy.

Average Directional Index (ADX):

ADX quantifies the strength of a trend, helping traders identify whether the market is trending or ranging.

ADX Equation (Smoothed):

Smoothed ADX = ((Prior Smoothed ADX \* 13) + Current TR) / 14

How to Use: ADX values above 25 suggest a strong trend, indicating potential buy or sell signals based on trend direction.

# 4. Fundamental Analysis

To perform fundamental analysis for stock market, it requires a deep knowledge about companies' fundamentals. Some of the companies' fundamentals include: **Data Collection:** Collect financial data for the target stock or company, including:

**Earnings Reports:** Quarterly and annual financial statements (Income Statement, Balance Sheet, Cash Flow Statement).

Market Data: Stock price, trading volume, and market capitalization.

Economic Indicators: Relevant macroeconomic data, such as interest rates and GDP growth.

Earnings Per Share (EPS):

Calculate EPS as:

EPS = (Net Income - Dividends on Preferred Stock) / Average Outstanding Shares

Use: Higher EPS indicates higher profitability, which can be a positive signal for investors.

Price-to-Earnings (P/E) Ratio:

Equation: Calculate P/E Ratio as:

P/E Ratio = Stock Price / EPS

Use: A lower P/E ratio may suggest an undervalued stock, while a higher ratio may indicate an overvalued stock.

Price-to-Book (P/B) Ratio:

**Equation:** Calculate P/B Ratio as:

P/B Ratio = Stock Price / (Total Assets - Total Liabilities)

Use: A P/B ratio below 1 may indicate that the stock is undervalued in relation to its assets.

Dividend Yield:

**Equation:** Calculate Dividend Yield as:

Dividend Yield = (Dividend per Share / Stock Price) \* 100

Use: Investors seeking income may prefer stocks with higher dividend yields.

Debt-to-Equity (D/E) Ratio:

Equation: Calculate D/E Ratio as:

D/E Ratio = Total Debt / Shareholder's Equity

Use: Lower D/E ratios indicate lower financial risk, but it's essential to consider industry benchmarks.

Free Cash Flow (FCF):

**Equation:** Calculate FCF as:

FCF = Operating Cash Flow - Capital Expenditures

Use: Positive FCF indicates the company's ability to generate cash after reinvesting in operations.

Discounted Cash Flow (DCF) Analysis:

**Equation:** Calculate the present value of future cash flows using the formula:

 $DCF = \Sigma (CFt / (1 + r)^t)$ 

Where CFt is the expected cash flow in year t, r is the discount rate.

Use: DCF helps estimate the intrinsic value of a stock by discounting future cash flows.

#### **Economic Indicators:**

Analyze relevant economic indicators (e.g., interest rates, GDP growth) that can impact the company's performance.

#### Qualitative Analysis:

Consider non-financial factors such as management quality, industry trends, and competitive positioning.

#### **Final Evaluation:**

Combine quantitative and qualitative findings to make an informed investment decision.

#### **Risk Assessment:**

Assess the risks associated with the investment, including industry risks, company-specific risks, and market risks.

#### **Continuous Monitoring:**

Continuously monitor company financials, market conditions, and economic indicators to adjust investment strategies as needed.

Fundamental analysis provides a comprehensive framework for evaluating the intrinsic value of stocks and making investment decisions based on a company's financial health and market conditions.

# 5. Sentimental Analysis

To understand market sentiments, we can use the following parameters and ideas:

Data Collection: Gather a diverse range of textual data sources that can influence market sentiment, including financial news articles, social media posts, earnings reports, and press releases.

**Text Preprocessing:** Perform text preprocessing to clean and prepare the data for analysis. Steps may include:

Tokenization: Splitting text into words or phrases.

**Stopword Removal:** Eliminating common words that carry little meaning.

**Lemmatization or Stemming:** Reducing words to their base form.

Removing special characters and punctuation. Sentiment Lexicons:

Utilize sentiment lexicons or dictionaries containing words or phrases with assigned sentiment scores (positive, negative, neutral). Assign sentiment scores to each word or phrase in the text data based on the lexicon.

#### Machine Learning Models:

Train machine learning models to perform sentiment analysis. (SVM is the preferred model).

#### Sentiment Scoring:

Calculate sentiment scores for each piece of text data, which represent the overall sentiment expressed in the text. This can be done by aggregating sentiment scores of individual words or phrases.

For example, using a simple method:

Sentiment Score = (Sum of Word Scores) / (Number of Words)

Entity Recognition: Identify and extract entities (e.g., company names, products) mentioned in the text, as sentiment towards specific entities can affect stock prices.

#### Time Series Analysis:

Analyze sentiment scores over time to identify trends and patterns. For instance, use moving averages to smooth sentiment trends.

#### Market Impact Analysis:

Investigate how sentiment changes in news or social media correlate with stock price movements.

Apply statistical methods to quantify the impact of sentiment on stock prices, such as

regression analysis:

Stock Price =  $\alpha$  +  $\beta$  \* Sentiment Score +  $\varepsilon$ 

**Sentiment Visualization:** Create visualizations like sentiment heatmaps or time series plots to provide a clear view of sentiment trends.

#### News Sentiment Aggregation:

Aggregate sentiment scores from multiple sources (e.g., news articles, tweets) to get a comprehensive view of market sentiment.

#### Thresholds and Alerts:

Set sentiment thresholds to trigger alerts or trading actions. For example, if sentiment becomes extremely negative, it could signal a potential buying opportunity.

#### Back testing:

Backtest trading strategies based on sentiment analysis to evaluate their historical performance. This involves simulating trades using past data to assess the strategy's effectiveness.

#### Integration with Trading Algorithms:

Integrate sentiment analysis into trading algorithms to automate trading decisions. For

example, use sentiment as an input feature to decide when to buy or sell stocks.

#### Continuous Learning:

Continuously update sentiment models and lexicons to adapt to evolving language and market conditions.

Sentiment analysis plays a crucial role in modern stock trading by providing insights into market sentiment and helping traders make more informed decisions. By combining natural language processing techniques with machine learning models, sentiment analysis can capture and analyze textual data at scale, offering valuable insights for both short-term and long-term trading strategies.

# 6. Case Results

#### 6.1 Performance Metrics

The performance of ATbot was rigorously evaluated using historical data spanning multiple years across various stock markets. The following key performance metrics were assessed:

#### Return on Investment (ROI):

ATbot's ability to generate profits was measured, considering both long-term and short-term trading strategies. The ROI for each strategy was calculated and compared to benchmark indices.

Risk Management: The bot's risk management strategies, including stop-loss orders and position sizing rules, were evaluated. This assessment aimed to determine the effectiveness of risk mitigation measures.

Volatility and Drawdowns: Volatility and drawdowns were analyzed to understand the bot's ability to handle market fluctuations. Low volatility and drawdowns indicate a more stable trading strategy.

Sharpe Ratio: The Sharpe ratio, which measures the risk-adjusted return, was computed. A higher Sharpe ratio implies a more efficient use of risk to generate returns.

#### Long-Term Investment Strategies:

ATbot demonstrated remarkable results in long-term investment strategies:

Over a two-year backtesting period, the bot consistently outperformed benchmark indices, such as the NIFTY 50, BANKNIFTY, FINNIFTY in terms of ROI.

The risk-adjusted returns, as indicated by the Sharpe ratio, were notably higher than the benchmarks, showcasing the bot's efficiency in managing risk while generating profits.

Through in-depth fundamental analysis and sentiment analysis of financial news, ATbot identified undervalued stocks and growth opportunities, contributing to its long-term success.

#### 6.2 Short-Term Trading Strategies

In the realm of short-term trading, ATbot exhibited the following outcomes:

High-frequency trading strategies, driven by machine learning models, allowed ATbot to capitalize on intraday price movements. It consistently outperformed traditional trading algorithms in terms of daily returns.

Dynamic risk management mechanisms effectively limited drawdowns during periods of market volatility. This adaptability proved crucial in preserving capital.

Sentiment analysis of real-time news and market reports empowered ATbot to respond swiftly to market sentiment shifts, resulting in timely buy/sell decisions.

# 7. Real-Life Tests

To understand the efficiency of ATbot, a test on chart patterns was done.



Picture 1: Identification of Chart patterns.

This is a classic example of **Symmetrical triangle pattern**, where it indicates a breakout in price, if three consecutive candles close above the upper band.

ATbot was able to understand the price breakout accurately and placed the trade on HINDALCO, and a 10-12% gain was achieved within a month (15-20 trading sessions).

Also, another test was done on UPL, where the company saw a sharp decline in quarter-on-quarter(QoQ) profits in the 2nd quarter, and it was also unable to match up with the market estimates, and went through a 6-7% correction. ATbot placed the trade in right time, and good gains were made.

# 8. Discussions

The results of ATbot's performance assessments highlight its potential to revolutionize trading strategies in the modern financial landscape. Its adeptness in both long-term and short-term strategies showcases the versatility of AI-driven trading algorithms.

The superior ROI achieved in long-term strategies underscores the bot's ability to harness predictive analytics through fundamental and sentimental analysis. By identifying patterns and undervalued assets, ATbot offers traders a powerful tool for optimizing profitability in a dynamic market.

In the domain of high-frequency trading, ATbot's adaptability and swift decision-making based on real-time sentiment analysis positions it as a formidable competitor. Its ability to generate consistent daily returns, while effectively managing risk, is a testament to the synergy between AI and financial expertise.

However, it's important to note that while ATbot exhibits promising results in backtesting environments, the real-world stock market is inherently unpredictable. Uncertainties, sudden market shocks, and unforeseen events can impact its performance. Continuous monitoring and fine-tuning are essential to adapt to changing market dynamics.

In conclusion, ATbot represents a pioneering step in the integration of AI and machine learning in trading strategies. Its ability to combine predictive analytics, sentiment analysis, and risk management makes it a valuable asset for traders seeking to optimize their investment decisions. As the financial markets evolve, ATbot stands ready to adapt and lead the way towards more data-driven and intelligent trading practices.

# 9. Strengths

Versatile Strategies: ATbot showcased its versatility by excelling in both long-term and short-term trading strategies. Its proficiency in fundamental analysis, sentiment analysis, and high-frequency trading positions it as a well-rounded tool for traders. Risk Management: The bot's risk management mechanisms, including dynamic stop-loss orders and position sizing, effectively controlled drawdowns during volatile market conditions. This is a crucial aspect for preserving capital and mitigating risk.

Adaptability: ATbot's ability to adapt to real-time market sentiment shifts through sentiment analysis of news and reports proved to be a valuable asset. It made timely buy/ sell decisions, highlighting its responsiveness to market events.

# 10. Areas of Considerations

Market Uncertainties: While ATbot performed admirably in backtesting environments, it is essential to acknowledge that the stock market is inherently unpredictable. Unforeseen events and market shocks can challenge its predictive capabilities.

**Continuous Monitoring:** The bot's performance relies on continuous monitoring and fine-tuning to adapt to changing market dynamics. Regular updates and adjustments are necessary to maintain its effectiveness.

**Regulatory Compliance:** Compliance with financial regulations and exchange rules is paramount. Ensuring that ATbot adheres to these regulations is vital to avoid legal complications.

# 11. Conclusion

In conclusion, ATbot represents a remarkable fusion of data science, machine learning, and financial expertise in the context of trading strategies. Its ability to harness predictive analytics, sentiment analysis, and risk management offers traders a potent tool to optimize their investment decisions.

While it demonstrates exceptional promise, it is crucial to recognize the ever-changing nature of financial markets. ATbot's real-world performance may vary due to unforeseen circumstances, underlining the importance of continuous monitoring and adaptation.

As technology continues to advance, and the financial landscape evolves, ATbot stands as a testament to the potential of AI-driven trading systems. Its results and capabilities underscore the significance of data-driven and intelligent trading practices in the modern era. The authors gratefully acknowledge the students, staff, and authority of Computer Science and Engineering Department for their cooperation in the research.

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# 18. Evolution of cloud computing technologies

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#### Abstract

This text explores the concept of cloud computing as a virtual space for storing and accessing information online. It contrasts traditional data storage methods with the advantages of cloud storage, emphasizing accessibility and convenience. The abstract highlights the definition of cloud computing as the rental of digital services when needed and the utilization of external storage and software. Overall, the text underscores the flexibility and benefits of cloud computing in contrast to traditional storage methods. We highlight some of the opportunities in cloud computing, underlining the importance of clouds and showing why that technology must succeed. Finally, we discuss some of the issues that this area should deal with.

Keywords: Characteristics, Deployment Models, Types of Cloud Computing.

# 1. Introduction

The cloud is a place to store information and programs online. The term "cloud" is actually used metaphorically for the Internet. Earlier, we used to save all the data on hard disk or memory card, which could not be recovered if it got corrupted. However, at present, if you store information in the cloud, you can access the necessary information anytime, anywhere, and utilize it.

If I have to define cloud computing in one word, then I would say it is renting digital services in exchange for money when needed. Cloud computing involves using others' storage, hardware, and software in exchange for a fixed amount of money when needed. It saves data to a remote server. From low-configuration machines to high-configuration machines, we can install all the software without utilizing our computer on that high-configuration machine.

**Example:** Think back to the days before the electricity power grid. After a while, when more power was needed, buying multiple generators was not sufficient, so the popularity of shared power generation and power grids increased.

# 2. Cloud Service Provider's Essential Characteristics

According to the US National Institute of Standards and Technology, cloud computing service providers will exhibit three characteristics:

I. **Resource Scalability:** The more the user or client desires, the more services can be provided. It seems like you're looking for information on resource

II. scalability in the context of cloud computing. Resource scalability in the cloud refers to the ability to dynamically adjust and allocate computing resources based on the changing demands of an application or workload.



Figure 1: Cloud Computing

**On-Demand Service:** The client can avail the service as needed and can adjust the level of service based on their requirements. On-Demand Service in the context of cloud computing refers to the capability of accessing computing resources or services as needed, without the need for direct human intervention. It emphasizes the idea that users can procure and utilize services on a flexible and pay-as-you-go basis, allowing for scalability and efficiency.

**Pay-As-You-Go:** Clients do not need to reserve the service in advance; they pay based on the actual usage. In a Pay-As-You-Go cloud model, users are charged for the computing resources they use, such as virtual machines, storage, and data transfer. This approach provides flexibility and cost efficiency, as users only pay for what they actually consume, and they can easily scale resources up or down based on their needs.

# 3. Cloud Computing Services

Cloud Computing Services encompass hardware, software, storage, backup, data recovery, web hosting, app development, databases, networking, email, and more.

# 4. Cloud Computing Service Providers

In 1999, a company called Salesforce first started providing cloud computing services. After that, big companies like Amazon, Google, Microsoft, Alibaba, Oracle, and IBM emerged as cloud service providers. Google has its own cloud called Google Cloud for various purposes, including Google Photos, Gmail, and Google Drive, utilizing it as part of its cloud computing infrastructure. When Twitter initially launched, it relied on Amazon Web Services. All major mail service providers such as Gmail, Yahoo, Dropbox, MediaFire, Netflix, online companies, and social media platforms like Facebook and Instagram utilize cloud computing to store videos, photos, and information. Notable cloud computing platforms include Amazon Web Services, Microsoft Azure, and Google Cloud. In addition to Google Apps, other popular cloud computing applications include Dropbox, Evernote, QuickBox, Google Drive, Moji, and Telegram.

# 5. Cloud Deployment Model

Deployment refers to the migration or movement of software, hardware, and computer resource storage from one host to another. If we host software and hardware through an internet remote server, it is called deployment. Why should we deploy software, hardware, and computing resources to cloud servers? Through the cloud server, we can use it in multiple places through the internet



Figure 2: CLOUD DEPLOYMENT MODEL

**Public Cloud:** It is a cloud that is open to all. Any person can use the service. The cost of the service is relatively low or free. An example of a public cloud is Amazon EC2. The advantage of this type of cloud is that anyone can use it. The disadvantage is that having multiple users in one place can lead to security problems. Ex – AWS

**Private Cloud:** In this type of cloud model, large companies and organizations use their own data center as a cloud to run their various services; it is called a private cloud. Ex -Microsoft Azure, VMware, and OpenStack

**Community Cloud:** Community refers to a community or group of people. A community cloud and a public cloud are shared by everyone, but the difference is that this cloud is limited to a specific community or group. Due to the fact that the number of users in this cloud is specific and limited, the security problem is less, but the cost is higher. Ex - AWS

**Hybrid Cloud:** Combination of Public, Private, and Community Clouds: These types of clouds are used for various specific tasks. If a bank puts the customer's private data in the private cloud and the public data in the public cloud, this entire cloud storage is called a hybrid cloud. Ex - Microsoft Azure

There are generally three types of cloud deployment models: public cloud, private cloud, and community cloud and hybrid cloud. Additionally, distributed cloud, multi-cloud, and inter-cloud are other variations

# 6. Cloud Service Models

This section of the paper outlines the different cloud delivery models. Cloud services are typically provided through three models, namely IaaS (Infrastructure as a Service), PaaS (Platform as a Service), SaaS (Software as a Service), STaaS (Storage as a Service) and NaaS (Network-as-aservice). These models offer distinct approaches to accessing and utilizing computing resources in the cloud environment.

IaaS, or Infrastructure as a Service: The infrastructure of these cloud services is leased, i.e., service providers rent PCs or virtual machines to clients and allow them to use them. An example of this type of service is AWS EC2 or Elastic Compute Cloud, where users can install all the necessary software starting from the operating system as they wish. The benefits of this service are that users can control everything themselves. However, the disadvantage is that they have to install and manage all the software themselves.

**PaaS or Platform as a Service:** This service does not directly rent the virtual machine but only leases the platform. In simpler terms, it rents the operating system (OS) or application programming interface (API). Users can install software required for work on this platform or create and develop apps, for example, Google App Engine and Microsoft Azure.



Figure 3: Cloud Service Model

SaaS or Software-as-a-service: In this service, you can rent a specific ready-made software or application to address the task you need. An example of such a service is Google Docs. It provides all the benefits of Microsoft Office; for instance, with Google Docs, you can create documents, excel sheets, PowerPoint presentations, and handle all tasks within this cloud service. **STaaS or Storage as a Service:** In this service, you will have the opportunity to store any data in cloud storage. Examples of such services are Google Photos and Google Drive, etc. You can upload any photo to Google Photos through a Gmail account and any file to Google Drive.

NaaS or Network-as-a-service: In this service, you can utilize the network infrastructure securely. VPN, a Virtual Private Network, is an exemplary feature of cloud computing that ensures a protected connection for users accessing resources over the internet. This technology encrypts data transmission, enhancing the overall security of the cloud computing experience.

# 7. Opportunities

Low Operating Cost: We can work with minimal cost of cloud computing where any required software or computer rental is available so considering the operating difficulty is sufficient.

Metered Service & Flexibility: Cloud computing can tailor services to its needs, offering a dynamic and scalable approach. With a pay-asyou-go model, you incur costs based on actual usage, ensuring cost-effectiveness. This flexibility allows businesses to adapt their computing resources to changing demands, optimizing efficiency and minimizing financial commitments.

Unlimited Storage: Abundant storage is accessible, alleviating concerns about limitations. You can acquire as much storage as needed to store data at an affordable price, without incurring any additional charges. This flexibility not only ensures efficient data management but also allows businesses to scale their storage requirements seamlessly as they grow. The availability of unlimited storage in cloud computing provides a scalable solution for organizations, eliminating worries about running out of space and offering a cost-effective approach to managing data resources.

Security: Data security is paramount in today's digital landscape. A reputable cloud computing company prioritizes and ensures robust security measures, safeguarding your information at every level. From encryption protocols to continuous monitoring, these companies employ cutting-edge technologies to protect against potential threats. By choosing a security-focused cloud service, users can trust in a comprehensive approach that extends across all aspects of their data, providing a secure and reliable computing environment.

User Experience and Satisfaction: Users benefit from a consistently updated and improved experience without disruptions, leading to higher satisfaction. Access to new features and improved functionality enhances the overall usability of applications and services.

Vendor Support and Compliance: Aligns with vendor support requirements as organizations stay within supported versions and configurations. Facilitates compliance with industry standards and regulations by ensuring that systems are up to date with the latest security and compliance measures.

# 8. Issues

Security: We lack direct control over the data stored in cloud storage, and we are unaware of its location within the cloud service provider's infrastructure. As this data is stored on foreign servers, there is a risk that, if hacked or accessed by a third party, sensitive government information may be compromised, potentially causing significant harm to the country. Entrusting important data to servers operated by foreign companies also poses inherent risks. Moreover, this lack of direct oversight can lead to uncertainties regarding the implementation of security measures and compliance standards. Organizations must carefully assess and choose cloud service providers with a robust track record in security and transparent practices.

Internet Connection: Cloud computing is entirely dependent on the Internet; therefore, a stable and reliable internet connection is essential for seamless operations. Inconsistent or slow internet speeds can lead to disruptions in accessing cloud-based applications, resulting in potential delays and decreased productivity. Organizations relying on cloud services should invest in robust internet infrastructure and consider implementing backup internet connections to mitigate the impact of any outages. Additionally, optimizing network configurations and utilizing technologies such as content delivery networks (CDNs) can enhance the overall performance of cloud applications, ensuring a smoother user experience even in challenging connectivity conditions.

Uncontrolled Process: The processing is handled by our service providers in a plug-andplay manner, leaving us with no control over the processing. While this approach provides convenience, it also introduces challenges related to customization and optimization of processes. Organizations may find it challenging to tailor processes to specific requirements or address unique workflows when relying solely on the predefined processes offered by service providers.

Depends on cloud providers: suggests that the reliability, features, and overall performance of a cloud-based service depend on the specific provider chosen. It highlights the importance of selecting a reputable and suitable cloud service provider based on the specific needs and requirements of an individual or organization. When considering cloud solutions, it's crucial to thoroughly evaluate different providers, taking into account factors such as security measures, service-level agreements (SLAs), data management practices, scalability, and overall customer support. The choice of a cloud provider can significantly impact the efficiency, security, and overall success of utilizing cloud computing services.

Cost: The expenses associated with cloud computing can be considerable, driven by the need for a persistent "always on" connection and the substantial usage of data brought back in-house. These costs may include ongoing connectivity charges and data transfer fees, and organizations should carefully evaluate their usage patterns to optimize spending and avoid unexpected financial implications.

# 9. Conclusion

Cloud computing is a technology that allows users to store and access data and applications over the internet instead of on physical hardware. It utilizes remote servers hosted on the internet to manage, process, and store data, providing flexibility and accessibility from anywhere. Essential characteristics of cloud service providers include resource scalability, on-demand services, and a pay-as-you-go model. Deployment models such as public, private, community, and hybrid clouds cater to diverse organizational needs. Service models encompass
Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). Notable cloud service providers include Amazon, Google, Microsoft, and others. While cloud computing offers opportunities like low operating costs and unlimited storage, security concerns and dependency on internet connectivity are notable challenges. Strategic planning is essential for organizations to leverage the benefits of cloud computing effectively

# 10. Future Scope

The future scope of cloud computing includes advancements in edge computing, security, integration with quantum computing, and Load balancing Uncontrolled Processes.

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# 19. Design and development of an automated prototype machine for grass-cutting and seed-sowing

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# Abstract

This paper presents the design and development of an automated agricultural prototype machine capable of performing grass-cutting and seed-sowing. The machine's design encompasses autonomous navigation, grass-cutting mechanisms, and precision seed-sowing capabilities. The development process involves integrating mechanical, electrical, and software components to create a versatile and efficient agricultural tool. The prototype undergoes rigorous testing to ensure functionality, safety, and performance in real-world agricultural environments. This innovative solution aims to enhance agricultural productivity and efficiency while reducing manual labour requirements.

Keywords: Cutting mechanism, seed-sowing mechanism, Arduino Microcontroller board, Automated prototype machine.

# 1. Introduction

Agricultural automation has become increasingly important in modern farming practices, offering the potential to improve efficiency, reduce labour costs, and enhance productivity. In line with this trend, this paper introduces the design and development of an automated agricultural prototype machine tailored for grass-cutting and seed-sowing. By leveraging advanced technologies in mechanical engineering, electrical systems, and software development, the prototype aims to address the labour-intensive nature of these agricultural tasks and promote sustainable farming practices.

The machine's autonomous capabilities enable it to navigate agricultural fields, efficiently execute grass-cutting operations, and accurately seed crops, thereby streamlining traditional farming methods. Through this innovative approach, the prototype seeks to minimize manual labour requirements, optimize resource utilization, and enhance overall agricultural productivity. The integration of cutting-edge technologies and robust design principles makes this prototype a potential game-changer in the agricultural sector, offering practical solutions to address the evolving needs of modern farming practices. This paper provides a comprehensive overview of the design, development, and testing phases of the automated agricultural prototype, highlighting its potential to revolutionize grass-cutting and seed-sowing processes in the agricultural industry.

# 2. Methods and Materials

To realize the design and development of the automated agricultural prototype for grass-cutting and seed-sowing, the following methods and materials were employed, with Arduino serving as the primary microcontroller board.

#### 2.1 Materials

- a) Arduino Microcontroller Board: The Arduino board serves as the central control unit for the automated prototype, facilitating the integration of sensors, actuators, and control algorithms.
- b) Motors and Actuators: High-torque DC motors were utilized for the grass-cutting mechanism, while precision actuators were employed for the seed-sowing module.
- c) Sensors: Various sensors, including ultrasonic distance sensors for obstacle detection and GPS modules for navigation, were integrated into the prototype to enable autonomous operation.
- d) **Cutting and Seeding Mechanisms:** Customdesigned cutting blades and seed-sowing mechanisms were fabricated to suit the requirements of grass-cutting and seed-sowing tasks.
- e) Chassis and Mobility Components: The physical structure of the prototype was constructed using lightweight yet durable materials, with appropriate mobility components such as wheels or tracks for field navigation.
- f) Electrical Components: Wiring, connectors, power supplies, and safety components were selected and integrated to ensure the proper functioning and safety of the automated prototype.

#### 2.2 Methods

- a) Arduino Programming: The Arduino microcontroller was programmed using the Arduino IDE, incorporating algorithms for autonomous navigation, obstacle avoidance, grass-cutting control, and precise seed-sowing.
- b) Mechanical Design and Fabrication: The physical structure, including the chassis, cutting mechanisms, and seeding modules, was designed using Computer-Aided Design (CAD) software and fabricated using appropriate manufacturing techniques.
- c) Electrical System Integration: The electrical components, including motors, sensors, and actuators, were integrated with the Arduino board, and the wiring and connections were carefully established to ensure reliable operation.
- d) **Testing and Iteration:** The prototype underwent rigorous testing to evaluate its performance in grass-cutting and seed-sowing tasks, with iterative improvements made based on testing results.

By leveraging Arduino as the main microcontroller board and integrating a range of materials and methods, the automated agricultural prototype was successfully developed to perform grass-cutting and seed-sowing tasks autonomously and efficiently. This approach demonstrates the potential for Arduino-based automation to revolutionize traditional agricultural practices, offering enhanced precision, efficiency, and labour-saving benefits.

# 3. Block Diagram



# 4. Results

The developed automated agricultural prototype, utilizing Arduino as the main microcontroller board, successfully demonstrated efficient grass-cutting and precise seed-sowing capabilities in agricultural field tests. The results of the field-testing phase revealed the following key outcomes:

Autonomous Navigation: The prototype effectively navigated through agricultural fields, demonstrating robust autonomous capabilities enabled by the Arduino-based control system. It efficiently maneuverer around obstacles and followed predefined paths, showcasing reliable field navigation.

**Grass-Cutting Performance:** The grass-cutting mechanism, controlled by the Arduino board, exhibited consistent and effective cutting of grass within the designated areas. The prototype's cutting efficiency contributed to the maintenance of well-manicured agricultural fields.

**Precision seed-sowing:** The seed-sowing module, integrated, and controlled by the Arduino microcontroller, demonstrated accurate and uniform seeding of crops in the designated areas. The precision seeding capabilities showcased the potential for optimized crop cultivation practices.

**Overall Efficiency and Reliability:** Throughout the testing phase, the automated prototype consistently operated with a high level of efficiency and reliability, showcasing its potential to reduce manual labour requirements and enhance agricultural productivity. These results underscore the effectiveness of the developed automated agricultural prototype, highlighting the successful integration of Arduino as the central control system for autonomous navigation, grass-cutting, and seed-sowing. The prototype's performance in real-world agricultural environments emphasizes its potential to revolutionize traditional farming practices and contribute to the advancement of automated agricultural technologies. The demonstrated results reaffirm the viability of Arduino-based automation in agricultural applications, offering promising prospects for improved efficiency and productivity in the farming industry.

# 5. Conclusions

The development and field testing of the automated agricultural prototype, leveraging Arduino as the primary microcontroller board, has demonstrated its potential to revolutionize traditional farming practices. The successful integration of autonomous navigation, grass-cutting, and precision seed-sowing capabilities underscores the viability of Arduino-based automation in agricultural applications. The following conclusions can be drawn from the development and testing of the prototype:

Enhanced Efficiency: The automated prototype showcased significant efficiency improvements, contributing to reduced manual labour requirements and optimized agricultural operations. The autonomous navigation and precise task execution capabilities offer the potential for substantial time and resource savings.

**Precision and Reliability:** The prototype's consistent performance in grass-cutting and seed-sowing tasks, controlled by Arduino, underscored its precision and reliability. The integration of advanced control algorithms facilitated accurate and uniform task execution.

**Potential for Industry Impact:** The successful development of the automated agricultural prototype signifies its potential to impact the farming industry positively. By streamlining grass-cutting and seed-sowing activities, the prototype offers practical solutions to enhance agricultural productivity and sustainability.

**Future Development Opportunities:** The results of the prototype's field-testing high-light opportunities for further development and refinement. Iterative improvements and the incorporation of additional features could

enhance the prototype's capabilities and versatility for diverse agricultural applications.

In conclusion, the successful design, development, and field testing of the automated agricultural prototype, with Arduino as the central control system, signifies a significant stride towards advancing automated farming technologies. The demonstrated efficiency, precision, and reliability of the prototype underscore its potential to revolutionize traditional farming practices and contribute to the evolution of modern, technology-driven agricultural methods. Incorporating Arduino-based automation presents promising prospects for the agricultural industry, offering practical solutions for enhanced productivity and sustainable farming practices.

# 6. Acknowledgement

We would like to show our gratitude to the Swami Vivekananda University, Barrackpore, and we thank the teaching and non-teaching staff of the Department of Computer Science and Engineering. Also, thanks to our parents and friends who all are directly or indirectly supported this research.

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# 20. Green computing in cloud infrastructures: A comprehensive analysis of environmental sustainability and energy efficiency

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# Abstract

This manuscript explores the intersection of cloud computing and environmental sustainability, focusing on the emerging field of green computing. As the demand for cloud services continues to rise, it becomes imperative to assess and enhance the environmental sustainability and energy efficiency of cloud infrastructures. This comprehensive analysis investigates various strategies, technologies, and best practices aimed at mitigating the environmental impact of cloud computing while optimizing energy consumption.

Keywords: Green Computing, Cloud Computing, Environmental Impact, Energy Efficiency, Sustainability, Green Cloud Services, Renewable Energy, Virtualization, Data Centers

# 1. Introduction

The goals of green computing are similar to green chemistry: reduce the use of hazardous materials, maximize energy efficiency during the product's lifetime, increase the recyclability or biodegradability of defunct products and factory waste. In the intricate landscape of modern technological ecosystems, the concept of green computing emerges as a beacon of sustainable innovation. From the compact confines of handheld devices to the sprawling expanses of colossal data centers, its significance resonates across diverse spectra of systems. Within the hallowed corridors of corporate IT domains, green computing initiatives stand as stalwart guardians, steadfastly committed tomitigating the environmental ramifications inherent in the operation of digital

infrastructures. Indeed, the weight of this environmental imperative looms large, casting a shadow over the collective consciousness of the industry. Statistics paint a stark portrait, revealing the staggering reality that the sector's environmental footprint extends far beyond mere abstraction. A formidable 5-9% of the world's total electricity consumption finds its voracious appetite satiated within the hungry maw of technological infrastructure, while more than 2% of all emissions bear witness to the profound impact of digital prowess. Amidst this labyrinthine tapestry of challenges and imperatives, the clarion call for transformation reverberates with unyielding urgency. Data centers, those hulking behemoths of digital prowess, and the sprawling networks of telecommunications infrastructure must heed the call to arms. The imperative is clear: a paradigm shift towards energy efficiency, the judicious repurposing of waste energy, and a steadfast embrace of renewable energy sources shall serve as the cornerstone of their endeavours.

For in the crucible of competition, where the fires of innovation burn brightest, survival hinges upon adaptability and foresight. The mantle of leadership shall be donned by those who dare to tread the path less traveled, those who dare to reimagine the contours of technological progress through the prism of sustainability. In the relentless march towards a greener tomorrow, the trajectory of progress finds its course charted by the guiding principles of green computing. Some believe they can and should become climate neutral by 2030. In recent years, the rapid proliferation of cloud computing technologies has led to a significant transformation in the way businesses and individuals access and utilize computing resources. While the cloud offers unparalleled flexibility and scalability, the environmental impact and energy consumption associated with large-scale data centers have raised concerns about sustainability. This research journal explores the intersection of green computing, cloud infrastructures, and environmental sustainability, aiming to provide a comprehensive analysis of energy-efficient practices within cloud computing environments. The overarching goal of this study is to examine the various strategies and technologies implemented in cloud infrastructures to mitigate the environmental footprint and enhance energy efficiency. With the increasing demand for computing resources and the escalating environmental challenges, understanding and implementing sustainable practices in cloud computing have become imperative The seminar report on "GREEN COMPUTING IN CLOUD COMPUTING" is outcome of guidance, moral support and devotion bestowed on me throughout my work. In the realm of content creation, we delve into the intricate dance of perplexity and burstiness, two quintessential pillars shaping the essence of textual expression. Embarking on this voyage, I extend my heartfelt gratitude, an ethereal tapestry woven with threads of appreciation, to all those who've served as beacons of inspiration throughout the labyrinthine corridors of seminar preparation. Foremost among these luminaries stands Mr. Ranjan Sir, a paragon of wisdom and custodian of knowledge, whose benevolent guidance and unwavering support have illuminated the path of my seminar endeavour. As lecturer and Head of Department in the hallowed halls of MCA at Swami Vivekananda University, Barrackpore, his eminence radiates across the intellectual landscape, casting shadows of profundity and enlightenment. Words, however, fail to encapsulate the depth of gratitude that permeates my being, as I find myself entwined in the embrace of Institute's nurturing bosom. A symphony of appreciation resonates, echoing through the corridors of academia, for the enriching ambiance and the harmonious synergy of the work environment bestowed upon me. Thus, in this tapestry of acknowledgment and appreciation, I find myself humbled by the magnitude of support and care bestowed upon me. With each stroke of gratitude, I traverse the labyrinth of indebtedness, guided by the beacon of communal benevolence and camaraderie.

# 2. Green Computing

Green computing in cloud computing refers to the practice of designing, using, and managing computing resources in an environmentally friendly and energy-efficient manner. It involves optimizing data centers and cloud infrastructure to minimize energy consumption, reduce electronic waste, and lower the overall environmental impact. Green computing in the context of cloud computing emphasizes the adoption of energy-efficient hardware, virtualization, renewable energy sources, and other sustainable practices to make data processing and storage more eco-friendly. Figure 1 describes a Green Computing Model.



Figure-1: Green computing model

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# 2.1 environmental impact of cloud computing

Cloud computing has become an integral part of our digital infrastructure, offering numerous benefits such as scalability, flexibility, and cost efficiency. However, it also comes with environmental implications. Here are some key factors contributing to the environmental impact of cloud computing:

## Energy Consumption:

Data centres, which form the backbone of cloud computing, require a significant amount of energy to operate and cool the servers. The energy demand is driven by the massive scale and continuous operation of these facilities.

The energy mix used by data centres plays a crucial role. If a data center relies heavily on fossil fuels, it can have a higher carbon footprint compared to facilities powered by renewable energy sources.

# Carbon Emissions:

The energy consumption of data centers contributes to carbon dioxide (CO2) emissions, which are a major factor in climate change. The carbon intensity depends on the energy sources used by the data centers.

# *E*-*Waste*:

Rapid technological advancements lead to the frequent replacement of hardware in data centers. The disposal of obsolete or damaged equipment contributes to electronic waste (e-waste) if not handled properly. E-waste contains hazardous materials that can harm the environment if not managed responsibly.

#### Resource Extraction

The production of electronic components requires the extraction of raw materials, contributing to habitat destruction, water pollution, and other environmental issues. This includes the mining of metals such as gold, silver, and rare earth elements used in servers and other hardware.

# Server Utilization and Efficiency

Inefficient use of server resources, such as low server utilization rates, can result in wasted energy. Optimizing resource allocation and improving server efficiency can help reduce the environmental impact.

# Renewable Energy Adoption

The adoption of renewable energy sources, such as solar or wind power, by cloud providers is a critical factor in mitigating the environmental impact. Many companies are making efforts to increase the share of renewables in their energy mix.

#### Regulatory Compliance and Industry Standards

Adherence to environmental regulations and industry standards can influence the environmental practices of cloud service providers. Governments and organizations are increasingly focusing on sustainability in data center operations.

Efforts are underway within the industry to address these environmental concerns as shown in Figure 2. Cloud providers are investing in more energy-efficient technologies, using renewable energy, and adopting sustainable practices to minimize their environmental footprint. As technology continues to evolve, ongoing efforts to improve efficiency and sustainability will be essential in reducing the environmental impact of cloud computing.



Figure-2: Environments impact

# 3. Analysing energy consumption on green cloud computing

Green cloud computing refers to the practice of using computing resources in an environmentally responsible and energy-efficient manner. Analyzing energy consumption in green cloud computing involves assessing various aspects of data centers, hardware, software, and operational practices. Here are key points to consider:

# Data Center Infrastructure

- 1. *Energy-Efficient Hardware*: The use of energy-efficient servers, storage, and networking equipment is crucial. Modern hardware designs often focus on optimizing power consumption without compromising performance.
- 2. 2. *Cooling Systems*: Efficient cooling systems, such as free-air cooling or liquid cooling, can significantly reduce the energy required for maintaining optimal temperatures in data centers.

# Renewable Energy Sources

*Power Supply*: Integration of renewable energy sources like solar, wind, or hydropower for powering data centers helps reduce the carbon footprint associated with electricity consumption.

# Virtualization and Resource Consolidation

- 1. *Server Virtualization*: Consolidating multiple virtual servers onto a single physical server can reduce the number of active servers, leading to energy savings.
- 2. Dynamic Resource Allocation: Implementing systems that dynamically allocate resources based on demand can optimize energy consumption by adjusting the infrastructure to meet actual needs.

# Energy-Aware Software

- 1. Optimized Algorithms: Developing and using energy-efficient algorithms can minimize computational requirements and reduce overall energy consumption.
- 2. Load Balancing: Efficient load balancing ensures that workloads are distributed evenly across servers, preventing the unnecessary operation of underutilized hardware. consumption.

# Monitoring and Management

1. *Energy Monitoring Tools*: Implementing monitoring tools to track energy consumption in real-time allows data center operators to identify inefficiencies and make informed decisions to optimize resource usage.

2. *Energy Management Policies*: Establishing and enforcing policies that prioritize energy efficiency in the data center's day-to-day operations.

# Lifecycle Management

End-of-Life Recycling: Proper disposal and recycling of outdated hardware components help minimize environmental impact and promote sustainable practices.

# Regulatory Compliance and Certification

- 1. *Compliance*: Adhering to industry standards and regulations related to energy efficiency ensures that cloud providers are accountable for their environmental impact.
- 2. *Certifications*: Seeking certifications such as ISO 14001 or the U.S. EPA's ENERGY STAR for Data Centers demonstrates a commitment to green practices.

# User Awareness and Collaboration

- 1. User Education: Educating users on energy-efficient computing practices and encouraging responsible usage can contribute to overall energy savings.
- 2. Collaboration: Collaborating with other cloud providers and industry stakeholders to share best practices and promote green initiatives.

By addressing these aspects, organizations can create a more sustainable and energy-efficient cloud computing infrastructure, reducing the environmental impact associated with digital services.

# 4. Carbon foot printing

Green computing, also known as sustainable or eco-friendly computing, focuses on reducing the environmental impact of information technology (IT) systems and practices. One important aspect of green computing is addressing the carbon footprint associated with IT operations. The carbon footprint in green computing refers to the total amount of greenhouse gas (GHG) emissions, particularly carbon dioxide (CO2), produced by the activities and processes related to computing and information technology.

Carbon foot printing in green computing, especially in the context of cloud computing, involves assessing and mitigating the environmental impact of computing activities. The carbon footprint is a measure of the total greenhouse gas (GHG) emissions, primarily carbon dioxide (CO2), associated with a particular activity, product, or service. In the realm of green computing and cloud computing, the goal is to minimize these emissions and promote sustainability. Figure 3 shows the Carbon usage per/year. Here's how carbon foot printing is relevant in this context:

- A. Data Centers and Energy Consumption:
  - 1. Measurement and Assessment: Carbon footprinting begins with measuring the energy consumption of data centers, which are crucial components of cloud computing infrastructure.
  - 2. Renewable Energy Usage: Assessing the carbon footprint involves determining the percentage of energy sourced from renewable resources, such as solar or wind power.
- B. Virtualization and Resource Optimization
  - 1. Server Consolidation: Virtualization technologies enable running multiple virtual machines on a single physical server, reducing the number of servers needed and, consequently, the energy consumption.
  - 2. Dynamic Resource Allocation: Smart resource allocation and de-allocation based on demand contribute to energy efficiency and lower carbon emissions.

C. Energy-Efficient Hardware and Technologies:

- 1. Energy Star Compliance: Choosing energy-efficient hardware, such as Energy Star-rated equipment, can help in reducing power consumption.
- 2. Green IT Practices: Implementing green IT practices, like using low-power processors and energy-efficient cooling systems, can further minimize the carbon footprint.
- D. Cloud Service Providers' Initiatives:
  - 1. Transparency and Reporting: Cloud service providers can transparently report their energy usage and carbon emissions, allowing users to make informed choices based on environmental impact.

- 2. Use of Renewable Energy: Cloud providers investing in and using renewable energy sources for their data centers contribute to a lower carbon footprint.
- E. Carbon Offsetting:
  - 1. Offset Programs: Some organizations engage in carbon offset programs, where they invest in projects that reduce or capture an equivalent amount of CO2 to compensate for their emissions.
  - 2. Certifications and Standards: Adhering to recognized standards and certifications, such as the Carbon Trust Standard, indicates a commitment to carbon reduction.
- F. Lifecycle Assessment:
  - 1. Full Lifecycle Analysis: Considering the entire lifecycle of hardware and software, from manufacturing to disposal, helps in understanding and mitigating environmental impacts.
  - 2. E-waste Management: Proper disposal and recycling of electronic waste contribute to reducing the carbon footprint associated with end-of-life equipment.
- G. Monitoring and Optimization:
  - 1. Continuous Improvement: Regularly monitoring energy usage and optimizing systems based on performance and efficiency data is essential for ongoing carbon footprint reduction.

In conclusion, carbon foot printing in green computing within the realm of cloud computing involves a comprehensive approach, addressing energy consumption, hardware efficiency, renewable energy usage, and responsible end-oflife practices. Organizations and cloud service providers play a vital role in adopting sustainable practices and technologies to minimize their environmental impact.



Figure-3: Carbon use per user/year

# 5. the efforts made by cloud service providers to adopt sustainable and eco-friendly practices

Cloud service providers have been making significant efforts to adopt sustainable and eco-friendly practices in recent years. These efforts are driven by a growing awareness of the environmental impact of data centers and a commitment to reducing carbon footprints. Here are some of the key initiatives and practices implemented by cloud service providers.

Cloud service providers have been making significant efforts to adopt sustainable and eco-friendly practices in recent years. These efforts are driven by a growing awareness of the environmental impact of data centers and a commitment to reducing carbon footprints. Here are some of the key initiatives and practices implemented by cloud service providers:

#### Renewable Energy Usage:

- Many cloud providers are investing heavily in renewable energy sources such as solar, wind, and hydroelectric power to meet their energy needs. They are either purchasing renewable energy directly or investing in projects that generate renewable energy.

# Energy Efficiency Improvements:

- Cloud provider are constantly working to enhance the energy efficiency of their data centers. This includes using more energy-efficient hardware, optimizing cooling systems, and adopting advanced technologies to reduce overall power consumption.

# Carbon Offsetting:

- Some cloud service providers are actively involved in carbon offset programs. They invest in projects that capture or reduce the equivalent amount of carbon emissions to offset the emissions produced by their data centers.

# Green Data Center Design:

- Providers are designing and constructing new data centers with sustainability in mind. This involves utilizing eco-friendly materials, implementing efficient cooling systems, and adopting innovative architectural designs to reduce environmental impact.

# Circular Economy Initiatives:

- Cloud providers are increasingly exploring the concept of a circular economy by promoting the reuse and recycling of electronic equipment. This involves extending the lifespan of hardware, refurbishing equipment, and responsibly recycling electronic waste.

# Transparent Reporting:

- Many cloud service providers are committed to transparency regarding their environmental impact. They publish annual sustainability reports that detail their energy consumption, carbon emissions, and progress toward eco-friendly goals.

#### Community Engagement and Advocacy:

- Cloud providers are engaging with local communities and industry stakeholders to promote sustainable practices. They also actively participate in industry groups and initiatives focused on advancing environmental sustainability in the technology sector.

#### Innovation in Green Technologies:

- Cloud providers are investing in and adopting innovative technologies that promote sustainability. This includes exploring new energy storage solutions, more efficient hardware designs, and advanced cooling technologies.

By adopting these practices, cloud service providers aim to reduce their environmental impact, meet sustainability goals, and contribute to the global efforts to combat climate change. As the demand for cloud services continues to grow, it is expected that these providers will continue to innovate and implement more sustainable practices in the future.



Figure-4: action taken by Microsoft to adopt sustainable and eco-friendly practices

# 6. Acknowledgment

The seminar report on "GREEN COMPUTING IN CLOUD COMPUTING" is outcome of guidance, moral support and devotion bestowed on me throughout my work. In the realm of content creation, we delve into the intricate dance of perplexity and burstiness, two quintessential pillars shaping the essence of textual expression. Embarking on this voyage, I extend my heartfelt gratitude, an ethereal tapestry woven with threads of appreciation, to all those who've served as beacons of inspiration throughout the labyrinthine corridors of seminar preparation.

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# 7. Conclusion

In conclusion, the adoption of green computing principles in cloud infrastructures is imperative for mitigating the environmental impact and ensuring the long-term sustainability of the digital ecosystem. The recommendations provided in this research paper aim to guide stakeholders in implementing environmentally conscious practices, fostering innovation, and creating a more sustainable future for cloud computing.

By prioritizing green computing, the cloud computing industry can contribute significantly to global efforts aimed at reducing carbon emissions and creating a more environmentally sustainable IT infrastructure.

# 8. future directions

#### Edge Computing and Green Initiatives

Exploring the integration of edge computing with green computing principles to optimize energy consumption at the edge of the network, reducing the need for centralized cloud data centers.

# Machine Learning for Energy Optimization

Investigating the use of machine learning algorithms to predict and optimize resource utilization in real-time, enabling dynamic adjustments to energy consumption based on workload characteristics

# Blockchain for Environmental Accountability

Examining the potential of blockchain technology to provide transparent and verifiable records of energy consumption and carbon emissions, fostering accountability and sustainability in cloud infrastructures

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# 21. Smell sensing and actuation using embedded device over the network

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#### Abstract

Smell is transmitted via the network using embedded device. An embedded device is a stand-alone device that manages a specific task inside a larger computing system. In this project we will use three type of fragrance. The fragrance are Rose, Sandal & Jasmine. First in this project we will determine which is which fragrance. Then it will be worked out how it can be sent and received over the network.

This study investigates how fragrance can be streamed or static over the network using Digital Smell Technology. Concepts from a variety of scientific fields, including electronics engineering, artificial intelligence, data science, chemistry, photonics, and machine learning, are revealed by the technology. The study of this paper will assist in a better evaluation of various smell who not present in that place. This study aims to detect the smell & then transmit scents over the network.

Keywords: Fragrance, embedded device, smart-Nose

# 1. Introduction

Only the three senses of sight, touch, and hearing—have been linked to internet communication thus far. Smell transfer over the internet is still not very common. The development of new technology centers on our sense of smell. One idea in virtual reality is digital smell. The computer systems now have some excellent features thanks to virtual reality. Usually, a combination of hardware and software causes the digital odor. The hardware is responsible for creating the smell, the software analyzes the smell generation and generates unique rule for each distinct smell, and finally the gadget emits the smell.

Olfaction, another name for smell, is the sensory organs' examination and identification of chemicals in the air. Scents come in two flavors: pleasant and unpleasant. A smell is the most neutral and all-encompassing sense. Every creature has an area they are blind to smell. The unique olfactory range of each creature is exclusively linked to its necessities for survival. Human senses consist of inherently existing within the environment and don't need should be actively pursued out or stayed away from.

Biologically, smell functions as a sensitive element that can interact with target molecules and ions to produce particular responses. Among the five senses in the human body is the olfactory sense. It's a complicated process whereby specialized cells in the nasal cavity identify odor molecules, which then send signals to the brain for interpretation. A book released by Cambridge University Press claims that during the 1800s, people would frequently distinguish between the "higher" senses of vision and audition, and the "lower" senses of taste, smell, and touch. In an era when, at least in the West, faith in science and technological advancement was almost absolute and bodily pleasures were viewed with suspicion, the senses of the intellect seemed to win a moral victory over the senses of the body. Or was difference more complex than that? Do the two categories of senses differ

from one another? Can they be categorised in the same way as they were back then, albeit based on more objective criteria? Humans need both vision and hearing to perform essential functions like Communication (reading, writing, and hearing), spatial orientation (perceiving depth and distance, direction perception for sound sources, and equilibrium), and body language interpretation, and many other essential tasks. Furthermore, the ability to perceive form and manipulate objects both finely and coarsely depends heavily on vision. Lastly, the mediums through which the arts (including dance, music, theatre, cinema, painting, sculpture, architecture, and photography) are expressed are vision and hearing. Taste, kinesthesia, and touch, and smell can only come close to displaying the magnificence of that sense (cooking, perfumery, and, to some extent, only when combined with dance, pantomime, pottery, sculpture, and vision. Additionally, they appear to be less widespread & more individualized, being more tied to feelings and emotions than to judgements and ideas.

# 2. Literature Review

Initially in the 1950s, Hans Laube developed the Smell-O-Vision [1], which allowed people to "smell" what was happening in the movie as it was being projected. Regrettably, the scent-releasing device's hissing noises, delayed scent delivery, and uneven scent distribution throughout the theatre were all caused by subpar technology. The first digital smell sensor device was called "Sensorama" (1960). It had multiple sensor actuators that produced vibration, sound, wind, and smell. The user of this system must sit in front of a display screen that has multiple sensory actuators installed in it. Today's "virtual reality" experiences are made possible by the idea of layering sensory stimuli to enhance a basic movie going experience [2].

Because artificial olfactory sensor systems can analyse chemical gases both quantitatively and qualitatively, they can be used in industrial domains that require routine safety monitoring. [3, 4]. Chemical sensor unit at the heart of the e-nose system transforms chemical data converted to digital signal, creating array that can react in multiple dimensions to particular volatile organic compounds (VOCs). To connect particular acknowledgment occasions to particular volatile organic compounds (VOCs), multimodal sensor array technology and multidimensional pattern recognition data processing technology are necessary.

Among the available sensors are organic dyebased colorimetric sensors, surface acoustic waves (SAW), metal oxide (MO)-based electrochemical sensors, conductive polymers (CPs), mass spectrometry (MS), and biomimetic biosensors [11]. The following sources provide more details about the e-nose system's sensor technology: Hangxun et al., Jha et al., Feng et al., Nazemi et al., Zheng et al., and Kim et al. [16, 5, 12–15].

Over the past five to six years, scientists have adopted the term "virtual reality" for a variety of purposes. A concept known as virtual theatre was developed as a result of one of the virtual reality experiments. It consists of movement-controllable seats, digital goggles, multipoint sound, electronic hand gloves, and digital scent. Subsequently, scientists proposed a completely new use for digital smell in order to add more realistic effects in games and movies. The pioneers of this amazing technology are Smith and Lloyd Bellenson, two bioinformatics and genomics specialists. The perfume companies provided the basic concept for this in order to advertise their products. This is the origin of digital scent technology.

Hans Laube created the smell-o-vision in the early 1950s. In 1999, DigiScents released a product known as the iSmell. In 2001, DigiScents closed due to some loss. Thus, TriSenx introduced Scent Dome in 2003 to identify smells codes. Internet cafes operated by japanese company "K-opticom" installed specially units called kaori Web (comprising of six distinct cartridges intended for various smells) in 2004 as part of an experiment that ran until 20 March, 2005. Sandeep Gupta, an Indian inventor, stated that demonstrate prototype device that produces scents at CES 2005 in same year, 2004. The Huelva University's researchers created an XML Smell in 2005 and worked to make it smaller. Concurrently, Thanko introduced a P@D Fragrance generator, USB gadget, and Japanese investigators revealed that they were working on 3D television that would have Feel and smell and be accessible by 2020. Scentcom, an Israeli company, demonstrated a device that generates smells. The Japanese researchers developed "the Smelling Screen" in March of 2013. Numerous developments and studies are taking place in this field.

Environmental monitoring makes extensive use of electronic nose models. Despite the fact that humans can use scents to react to dangerous situations, the natural olfactory system is easily fatigued [17, 18]. E-nose technology is essential because It is challenging to monitor offensive smells in the field on a constant basis. High sensitivity, the ability to standardize VOC mixtures, and signal transmission for non-specific chemical gas exposure are requirements environmental monitoring technology. for Commercial environmental monitoring sensors are currently only used in limited capacities due to a number of issues, including high durability, repeatability, standardization, and detection limits-all of which are essential for enabling operation in unfavorable environmental conditions. [19, 20].

# 3. Methodology

Research Methodology is the science of conducting inquire about or tackling inquire about issues methodically. To realize the specified investigative objective, what can utilize diverse significant methods or methods? For tending to the investigate questions and goals of this consider, the exploratory approach is used. An exploratory think is a critical way of having a modern understanding of the issues, and it moreover makes a difference clarify the issues. Writing survey and overview are utilized as a inquire about technique in this thesis. A to begin with writing audit is conducted to get it the fundamental concept of cloud computing and how distinctive nations can utilize the cloud as a benefit from the provider.

A methodology needs to be created for the selected problem by the researcher. The process may differ even though the two problems have the same method. Assessing the efficacy and suitability of a selected research method is necessary for the researcher to arrive at the optimal study outcome. It must be evident how to apply a specific approach that is appropriate for the given situation. After the study is finished, the methodology must be explained so that others can appreciate the importance of the research and how it was conducted. Additionally, it gives the researcher the opportunity to discuss each action taken, potential causes, the research's strengths and limitations.

# 3.1 Methodology designing concept

# 3.1.1 Data collection

Data collection is a must while following analyzing the behavior of resulted values.

#### 3.1.2 Study of the requirements

The minimum resources required for the perspective of the research work must meet as needed.

#### 3.1.3 Using software

Jupyter Notebook (Python) is needed to the whole environment to research the circumstances created.

# 3.2 Data analyzing

Giving the data will be analyzed and studied.

# 3.2.1 Effectiveness measuring of the research

Effectiveness measurement is a primary step in how the research work is affecting the current system. Data analysis through the graph will provide much and efficient data to measure the impacts overall.

#### 3.2.2 Scent synthesizer

Scent synthesizers are electronic devices that produce a scent based on a digital file that is transmitted over the internet.

# 3.2.3 iSmell

The iSmell Personal Scent Synthesizer is a compact gadget that connects to a computer via a USB port. You can power this device with any regular electrical outlet.

# 3.2.4 Cartridge

When the signals are sent from the computer, the chemicals in the cartridge—such as synthetic

or natural oils—are activated by heat or air pressure.

#### 3.2.5 Scentography

Scentography is a tool that enables the integration of fragrances into conventional digital media, including websites, games, and DVDs. Figure 1 shows the block diagram of Smell detection process. Figure 2 shows the Transmission model of smell.



Figure 1: Detection of Smell

An apparatus called the "electronic nose" is able to detect odors more precisely than the human nose. A chemical detection mechanism is what makes up an electronic nose. The electronic nose was created to replicate human smell, which is a non-separate mechanism that perceives flavor and smell as a universal fingerprint. The sensor array, pattern reorganization modules, and headspace sampling are the main components of the instrument, which together produce signal patterns that are used to characterize smells. The three principal elements of the smart nose are sample delivery system, the computing system, and the detecting system.

The method used to deliver the sample: This method allows the volatile compounds or sample to generate headspace, which is a fraction that is analyzed. The electronic nose's detection system receives this head space after that from the system. The mechanism for detection: The reactive portion of the instrument is the detection system, which is made up of several sensors. When the sensors come into contact with volatile compounds, they react by changing their electrical properties. The computing system: Every sensor in the majority of electronic noses is uniquely sensitive to every molecule. On the other hand, receptor proteins that react to particular smell molecules are employed in bioelectric noses. Sensor arrays that respond to volatile compounds are used in the majority of electronic noses. The sensors record a particular response that is transmitted into the digital value whenever they detect any smell.



Figure 2: Transmission Model of Smell

This technology functions in conjunction with an smart nose and an olfactometer. An Olfactometer is a device that measures & identifies smell dilution. They are employed to determine a substance's threshold for odor detection.

Olfactometers measure intensity by introducing an odorous gas, which serves as standard against which another odors are measured. An smart nose, is a gadget that can identify the distinct elements of an odor by analyzing the chemical composition of those elements. Chemical detection and pattern recognition are its two main mechanisms.

The smart nose functions as a way to detect scent. Scent range is similar to the color range in that any given smell is the indexed smell of the primary scents in the scent range. Considering the chemical makeup and its place in the scent spectrum, an smart nose can distinguish between thousands of different smells. The chemical composition and scent spectrum of the smell are used to index it. Next, olfactory signal processing is used to digitally code and store each indexed scent in a small file. Digital file is attached to an email sent to the recipient's computer or content from the World Wide Web. Personal scent synthesizer on receiving end will replicate the scent when the user opens the file, and the air cannon will direct the scent into the user's nose. The data regarding the smell are contained in the digitally encoded file that is delivered. There will be vaporized smell released.

# 4. Conclusion

The new Internet era, as well as digital scent and smell technologies, are introduced in this paper. Artificial intelligence is the world in which we currently live. The thesis looks at what engineering, mechatronics, and software development students can learn while designing, building, and programming an smart nose. This will serve as a manual for students who are unfamiliar with embedded device and aid in their understanding of embedded systems, infrared sensors, microcontrollers, and how to create an artificial intelligence nose using embedded device.

The intriguing field of electronic scent and odor detection, identification, and analysis is unlocked by smart nose technology, opening up new avenues for creative inquiry and auspicious applications. The food, health, and drug industries, safety and criminal justice, as well as the environmental and agricultural sectors, have all shown interest in Smart Nose, a device that mimics the ability to smell in humans & has attracted a lot of attention.

Scents have a powerful attraction on humans. Due to its strong associations with memory and emotions, scent is a powerful tool for idea stimulation. The user should be able to see, hear, and smell things all at once thanks to the system's rich multimedia experience. One technological advancement in scent detection is smart nose.

This technology works best in these industries.

A. E-commerce: Live shopping experiences are made possible by this technology. This enables the purchase of food, beverages, and fragrances from distant locations.

B. Medical: Aromatherapy is a technique that uses different scents to treat specific illnesses. It helps distinguish between various brain disorders.

C. Education: In science, geography, and history classes, scent can be a helpful teaching tool.

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# 22. Exploring on automated pain detection using machine learning

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# Abstract

In recent years, there has been a burgeoning interest in utilizing machine learning techniques to automate pain detection, with the aim of improving objectivity and efficiency in the assessment process. This paper presents a comprehensive review and analysis of the current landscape of automated pain detection using machine learning algorithms. The paper delves into the diverse methodologies employed for automated pain detection, exploring modalities such as facial expressions, physiological signals, and vocal features as input data for machine learning models. A critical evaluation of the strengths and limitations of each modality is undertaken, with a particular emphasis on the significance of employing multimodal approaches to comprehensively capture the intricate nature of pain experiences. The study examines the integration of computer vision, machine learning, and deep learning techniques with the Internet of Things (IoT) in the context of an IoT-based noninvasive automated patient discomfort monitoring/detection system. Furthermore, the paper reiterates its focus on ethical considerations and challenges related to automated pain detection. It critically analyzes issues pertaining to privacy, consent, and potential biases within machine learning models. Emphasizing the need for addressing these ethical concerns, the paper advocates for the responsible development and deployment of automated pain detection systems. The ethical discourse underscores the commitment to ensuring the ethical integrity of these technologies in healthcare settings.

Keywords: Internet of Things(IoT), Machine Learning, Pain detection, RCNN, sensor.

# 1. Introduction

Definitions of pain have aimed to articulate fundamental features that characterize all pain experiences and distinguish them from other sensations. The widely accepted definition endorsed by the International Association for the Study of Pain (1979) centers on multidimensional distress, describing pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage or described in terms of such damage." While disagreement exists regarding the necessary and sufficient features for defining pain, Williams and Craig (2016) [1] advocate for explicit recognition of cognitive and social aspects, while common ground is found in acknowledging the dominance of emotional qualities in the sensory experience.

Various research studies on acute pain have indicated that Electrodermal Activity (EDA) can serve as an objective indicator of emotional distress associated with pain. In a study conducted by Cruz-Molina in 2018[2], the correlation between heat pain perception and skin conductance (SC) was explored, revealing a positive association between changes in sudomotor activity and temperature perception.

Additionally, Loggia et al. in 2011 [3] demonstrated increased heart rate (HR) and SC in response to more intense pain stimuli in healthy adult males. Susam et al. (2018) [4] employed HR, blink reflexes, and EDA to identify pain responses to electrical shock. In the case of children, SC variables were found to differentiate painful from non-painful tactile stimulation in newborn infants [5].

Moreover, Gruss et al. [6] achieved a noteworthy accuracy rate of 90.94% in classifying pain tolerance thresholds by combining EDA, electromyography, and electroencephalography. These studies collectively highlight the potential of EDA and related physiological measures in objectively assessing and understanding pain experiences across different populations and pain stimuli.In the realm of healthcare, a transformative revolution is underway, driven by the integration of cutting-edge technologies such as the Internet of Things (IoT) and advanced machine learning. This article introduces an innovative IoT-based noninvasive automated patient discomfort monitoring/detection system that integrates computer vision and deep learning. Departing from traditional wearable sensor and visionbased approaches, this system utilizes an IP camera device at its core, eliminating the need for cumbersome wearables and offering a more seamless and patient-friendly monitoring solution.

The system employs the Mask-RCNN method for extracting key points on the patient's body, crucial for monitoring body movement and posture and providing essential data for accurate discomfort detection without intrusive physical sensors. This groundbreaking approach signifies a paradigm shift in patient monitoring, showcasing the potential of advanced technologies to enhance healthcare services.

# 2. Literature Review

# 2.1 Overview of Pain's: Provides an introduction to different types of Pain's

Pain, being a multifaceted and subjective encounter, stands as a pivotal indicator of distress within the human body. Figure 1 shows different types of pain. It spans a spectrum from acute, signaling immediate issues, to chronic, persisting over an extended period. Presenting in various forms, pain presents a considerable challenge in healthcare due to its inherently personal and subjective nature. This overview endeavors to shed light on the manifold types of pain that individuals may undergo, thereby establishing a groundwork for delving into the realm of automated pain detection through machine learning.



Figure 1 Different types of Pain

# 2.1.1 Acute Pain

Acute pain denotes a transient and typically immediate discomfort resulting from injury, surgery, or identifiable causes. It acts as a protective mechanism, signaling potential harm and prompting individuals to take action to alleviate the underlying issue. Typically short-lived, acute pain resolves as the underlying cause is addressed.

# 2.1.2 Chronic Pain

In contrast, chronic pain persists over an extended period, often for months or even years. It may stem from conditions such as arthritis, nerve damage, or unresolved injuries. Unlike acute pain, chronic pain serves no apparent protective function and significantly impacts an individual's quality of life, presenting physical and emotional challenges.

# 2.1.3 Neuropathic Pain

Neuropathic pain emerges from damage or dysfunction in the nervous system, leading to abnormal signaling and perception of pain. Conditions like diabetic neuropathy, sciatica, and certain neurological disorders can cause neuropathic pain. This type of pain is often described as burning, tingling, or shooting and can be challenging to manage with traditional pain relief methods.

# 2.1.4 Inflammatory Pain

Inflammatory pain arises from the activation of the body's immune response, causing inflammation. Conditions such as rheumatoid arthritis, inflammatory bowel disease, and infections can trigger inflammatory pain. It often presents with redness, swelling, and heat in the affected area, and addressing the underlying inflammation is crucial for relief.

# 2.1.5 Nociceptive Pain

Nociceptive pain stems from the activation of nociceptors, specialized sensory receptors responding to harmful stimuli. It further categorizes into somatic and visceral pain, originating from tissues like muscles and skin, and internal organs, respectively. Nociceptive pain is usually well-localized and serves a protective function.

# 2.1.6 Psychogenic Pain

Psychological variables including stress, worry, and sadness can have an impact on psychogenic pain. Psychogenic pain may not have an obvious physiological basis, in contrast to other forms of pain. It emphasizes how the mind and body work together to shape pain perception in a complex way.

Automated pain detection systems, particularly those leveraging IoT and deep learning techniques, hold promise in revolutionizing pain understanding and management. By incorporating physiological signals, facial expressions, and relevant biomarkers, these systems aim to offer a more holistic and accurate representation of the patient's pain experience. The overview of different pain types lays the groundwork for exploring how machine learning can contribute to more effective and objective pain detection in healthcare, ultimately enhancing patient outcomes and quality of life.

# 2.2 Traditional methods of Pain Detection: Describes traditional methods of detecting Pain's

Pain, as a intricate and individualized experience, has long been a focal point in healthcare, demanding accurate and prompt detection for effective treatment. Conventional approaches to pain detection have heavily relied on subjective assessments, patient self-reporting, and observable physiological responses. This exploration first delves into the foundational aspects of these traditional methods before exploring the transformative potential of automated pain detection using machine learning.

# Subjective Assessments:

• Traditional pain detection methods frequently involve subjective assessments, where healthcare professionals depend on patients to verbally express their pain levels. While this approach is crucial, it is inherently constrained by individual variations in pain tolerance and the subjective interpretation of pain intensity. The reliance on patient self-reports introduces variability and complications in obtaining an objective understanding of the pain experience.

Visual Analog Scales have been a prevalent tool for quantifying pain intensity, as shown in Figure 2:

• Visual Analog Scales have been a prevalent tool for quantifying pain intensity. Patients are instructed to mark their pain level on a linear scale, offering a numerical representation of their subjective experience. Despite its widespread use, VAS is susceptible to individual interpretation and may fall short in capturing the multifaceted nature of pain, including its emotional and cognitive dimensions.



Figure 2: Visual Analog Scale (VSA) for pain intensity

Physiological Measures:

• Another traditional approach involves monitoring physiological responses to pain. This includes assessing parameters such as heart rate, blood pressure, and electromyography (EMG). Physiological measures provide objective data, but they may not always correlate directly with pain perception. Additionally, these measures may be influenced by factors other than pain, making them less specific indicators.

Observational Pain Scales:

• Particularly relevant in non-verbal populations, such as infants or individuals with communication challenges, observational pain scales rely on the assessment of observable behaviors. Facial expressions, body movements, and vocalizations are analyzed to infer pain levels. While these scales are valuable, they are often context-dependent and may not account for variations in pain expression across individuals.

Challenges in Traditional Methods:

• Traditional pain detection methods face challenges related to the subjectivity of self-reports, the limited ability to capture the full spectrum of pain experiences, and the dependency on external observers. These challenges highlight the need for more objective and comprehensive approaches to pain assessment.

While traditional methods have provided valuable insights into pain detection, the evolving landscape of healthcare calls for more sophisticated and objective approaches. Automated pain detection using machine learning emerges as a promising avenue, aiming to revolutionize the way we understand and respond to pain in the human body. As this field advances, the synergy between traditional methods and machine learning holds the key to unlocking new possibilities in pain assessment

# 2.3 Discusses the use of Machine learning in Pain detection and Human health

The convergence of machine learning (ML) and human health has given rise to groundbreaking solutions, particularly in the field of pain detection. Traditional methods of assessing pain often rely on subjective measures, making it challenging for healthcare providers to obtain accurate and timely information. The introduction of machine learning technologies represents a paradigm shift, offering a more objective and efficient approach to automated pain detection. This exploration delves into the transformative potential of machine learning in the context of pain assessment and its broader implications for human health.

Challenges in Traditional Pain Assessment:

• Traditional pain assessment methods, primarily relying on self-reporting and subjective interpretation, face inherent limitations due to the variability in individual experiences. This subjectivity poses challenges in both clinical and research settings, where precise and objective pain evaluation is crucial for effective treatment planning and medical research.

- The Promise of Machine Learning in Healthcare:
  - Machine learning, as a subset of artificial intelligence, has demonstrated remarkable capabilities in analyzing vast datasets and identifying complex patterns. In the context of healthcare, ML algorithms hold the promise of providing more accurate, objective, and timely assessments, transcending the limitations of traditional approaches. Automated pain detection using ML has emerged as a transformative application, aiming to enhance the precision and efficiency of pain assessment.

Integration of Machine Learning in Pain Detection:

• Automated pain detection using machine learning involves the utilization of diverse data sources, including physiological signals, facial expressions, and other biomarkers. These data are processed by ML algorithms, which learn patterns and associations to discern pain levels. This holistic approach allows for a more comprehensive understanding of pain, capturing nuances that may be overlooked by conventional methods.

Wearable Sensors and Beyond:

• Early applications of ML in pain detection often revolved around wearable sensors, capturing physiological responses to pain. However, recent advancements extend beyond wearables, incorporating noninvasive technologies such as computer vision and the Internet of Things (IoT). These technologies enable continuous monitoring without the need for intrusive devices, enhancing patient comfort and compliance.

Case Studies in Automated Pain Detection:

• A notable example is the development of an IoT-based noninvasive automated patient discomfort monitoring system. This system utilizes an IP camera to detect body movement and posture, eliminating the need for wearable devices. Deep learning algorithms, such as the Mask-RCNN method, extract key points on the patient's body, providing valuable information for assessing discomfort levels. Experimental evaluations of such systems have demonstrated high accuracy, validating their potential for real-world applications.



Figure 3: Work flow of pain recognition process

Th exploration of automated pain detection using machine learning signifies a paradigm shift in the assessment of human health as shown in Figure 3.

Implications for Human Health:

• The integration of machine learning in pain detection transcends individual applications, holding broader implications for human health. By providing objective and real-time assessments, ML contributes to more informed clinical decisions, personalized treatment plans, and improved patient outcomes. The ability to monitor pain continuously facilitates early intervention, particularly in chronic conditions, leading to enhanced quality of life for patients.

Challenges and Ethical Considerations:

• Despite the transformative potential, challenges persist, including ethical considerations, data privacy, and interpretability of ML models. Striking a balance between innovation and responsible use is imperative to ensure the ethical deployment of machine learning technologies in healthcare.

The exploration of automated pain detection using machine learning signifies a paradigm shift in the assessment of human health. By leveraging advanced technologies, such as computer vision and IoT, ML-driven pain detection systems offer a more objective, efficient, and patient-friendly approach. As research and development in this field progresses, the integration of machine learning not only revolutionizes pain assessment but also sets the stage for broader advancements in healthcare, marking a pivotal moment in the intersection of technology and human well-being.

# 2.4 Recent Research on Automated Pain Detection Using Machine Learning: Reviews recent research On Automated Pain Detection Using Machine Learning

Recent strides in the healthcare domain have witnessed a notable upswing in the exploration of automated pain detection utilizing machine learning (ML) techniques. This burgeoning field of research aspires to transform pain assessment by providing objective and efficient methods that transcend the limitations of traditional subjective measures. The following review offers an overview of the current landscape, highlighting key trends, challenges, and potential implications for patient care.

A noteworthy contribution to this realm is the research conducted by Winslow, Brent & Kwasinski, Rebecca & Whirlow, Kyle & Mills, Emily & Hullfish, Jeffrey & Carroll, Meredith (2022) [7]. This study focuses on developing a novel approach to objectively quantify acute pain experienced by individuals. The research involved 41 human subjects who underwent acute pain induction using the cold pressor test, a well-established method for inducing pain. Electrocardiography (ECG) was employed by the researchers to monitor the subjects, capturing their physiological responses during the pain-inducing procedure. This innovative approach aims to enhance the precision and reliability of pain assessment, marking a significant step forward in the integration of machine learning techniques into healthcare practices.



Figure 4: Pain detection classification model

The main objective of the study was to utilize Electrocardiogram (ECG) data for the creation of pain classifiers based on respiratory and heart rate variability features. These features were computed across time, frequency, and nonlinear domains, providing a comprehensive analysis of physiological responses linked to acute pain. Logistic regression classifiers were employed by the researchers to formulate two distinct scenarios for pain detection: one designed for laboratory or clinical settings and another tailored for field or ambulatory use (shown in Figure 4).

The obtained results showcased promising outcomes, with the laboratory/clinical scenario achieving an impressive F1 score of 81.9%, while the field/ambulatory scenario achieved a commendable F1 score of 79.4%. The F1 score, serving as a metric that balances precision and recall, provides insights into the model's accuracy in identifying instances of pain. The elevated F1 scores strongly indicate the effectiveness of the developed classifiers in precisely quantifying acute pain, underscoring their potential utility in diverse settings and scenarios.

The project's main goal was to automatically identify pain from facial expressions in Hassan, T., Seuß, D., Wollenberg, J., Weitz, K., Kunz, M., Lautenbacher, S., & Schmid, U. (2019) [8]. Notably, other projects have investigated the use of machine learning techniques to combine facial activity with physiological signals like skin conductance, ECG, and EMG, or with other modalities like vocalizations. These initiatives have shown that combining data from several modalities can increase the rate at which pain is recognized shown in Figure 5.



Fig. 1. General steps involved in developing an automatic pain detection system based on facial expressions. The boxes marked in gray highlight the elements that are covered in detail in this survey.



The study discusses a number of difficulties related to data collection and the creation of learning techniques. Future directions for research are also identified. The authors stress the significance of establishing and designating a dataset, or a combination of datasets, for the purpose of benchmarking automatic pain detection techniques. They also note the need for more datasets that satisfy additional requirements. Insights into the state of automatic pain detection research are provided by this thorough analysis, opening the door for problems to be solved and the field to advance.

In Cheng, D., Liu, D., Philpotts, L. L., Turner, D. P., Houle, T. T., Chen, L., ... & Deng, H. (2019) [9], the analysis of the extracted outcome data is conducted using RevMan V.5.2.1 software and R V3.3.2. RevMan is widely acknowledged for its utility in conducting systematic reviews and meta-analyses, while R serves as a robust statistical programming language commonly employed in data analysis and visualization.

The study, aiming to comprehensively evaluate the prediction accuracy of machine learning models in the medical and computer science domains, adheres to a robust methodology. This methodology encompasses a meticulous literature search, eligibility screening utilizing Covidence, data extraction stored in the Systematic Review Data Repository, and an in-depth analysis using RevMan and R. The outcomes measured extend beyond accuracy, encompassing crucial aspects of utility, and the risk of bias is evaluated using a state-of-theart tool. This research significantly contributes to the ongoing discourse on the application of machine learning in predictive modeling within these critical domains.

The goal of the paper by Chen, J., Abbod, M., & Shieh, J. S. (2021) [10] is to clarify the mechanisms underlying stress and pain, look at how they relate to one another, and investigate detection tools and assessment techniques. The authors also explore the field of wearable sensor-based health-monitoring systems, highlighting and debating its potential to alleviate the unequal distribution of resources for pain diagnosis and treatment around the globe. In this situation, wearable sensors are a possible solution due to their inherent advantages, which include their low cost and user-friendly characteristics.

The essay emphasizes how people all throughout the world are becoming more conscious of the importance of pain management and how to promote it. Because of their low cost and simplicity of use, wearable sensors are well-positioned to provide an excellent way to close the global resource gap in the diagnosis and treatment of pain-related conditions. Wearable sensors become more than just data gathering tools when combined with AI algorithms and cloud computing capabilities. They become the cornerstones of all-encompassing health monitoring and treatment systems.

Moreover, the article emphasizes that wearable sensors, through the analysis and quantification of pain and stress, present an opportunity to address global challenges in pain and stress management. Figure 6 describes the Placement of sensor on human body. By leveraging these advanced technologies, there is potential for a paradigm shift in healthcare, providing more effective and personalized solutions for individuals dealing with pain and stress issues on a globally.



Figure 6 Placement of sensors on human body.

In Ahmed, I., Jeon, G., & Piccialli, F. (2021) [11], the authors provide an automated monitoring and detection system for patient discomfort that is based on the Internet of Things. The all-inclusive solution includes a top-view IP camera that records video clips. Using semantic features, the implemented solution uses the Mask-RCNN architecture to detect critical points on

different parts of the patient's body. Following that, these landmarks are converted into the patient's primary organs using association rules. The distance between successive key points across frames is used to analyze the discomfort within these organs. Body organ movements are classified as normal or uncomfortable based on the use of temporal and distance thresholds.

A recorded dataset is used to test the pretrained model and evaluate its performance. A variety of performance metrics are included in experimental evaluations, including as accuracy, precision, recall, True Positive Rate (TPR), False Positive Rate (FPR), True Negative Rate (TNR), and Misclassification Rate (MCR). The True Detection Rate (TDR) and False Detection Rate (FDR) for each body organ in each video sequence are measured to show how robust the system is. The efficacy of the suggested approach is demonstrated by its average TPR of 94% with a 7% FPR.

The authors suggest potential extensions for their work, envisioning the recording of high-resolution datasets to capture not only patients' movements but also their facial expressions. Furthermore, they propose the development of real-time interactive automated discomfort detection systems, offering assistance during emergencies as shown in Figure 7. Overall, this work presents a promising and robust approach to automated patient discomfort monitoring, paving the way for potential advancements in healthcare technology.



Figure 7 IoT-based Patient discomfort detection system.

The research on automatic methods supporting pain assessment is presented in the publication by Werner, P., Lopez-Martinez, D., Walter, S., Al-Hamadi, A., Gruss, S., & Picard, R. W. (2019) [12]. It presents several effective ideas and approaches that show promise. Understanding modalities and multimodal systems, applying restricted data, learning from weak and ordinal ground truth, and temporally contextualizing



Figure 8 General architecture of Mask CNN used for patient discomfort detection.

model personalization are important areas of improvement.

Even though these areas have seen significant gains, the authors stress that more work is necessary before these developments may have an impact on clinical practice. Mask-RCNN(as shown in Figure 8) architecture to detect critical points on different parts of the patient's body. This entails making more progress in the fields of knowledge and technology, obtaining the necessary information, and improving and showcasing the usefulness of recognition systems in practical applications. The demand for ongoing attention to these areas emphasizes the focus to converting research discoveries into useful applications that might have a positive impact on clinical settings' approaches to pain evaluation.

# 3. Conclusion

The evolution of machine learning models for pain detection represents a promising frontier in healthcare, marked by significant advancements from researchers across multidisciplinary fields. The discussed studies, spanning logistic regression classifiers, facial expression analysis, and wearable sensor-based health-monitoring systems, collectively contribute to advancing the understanding and application of automatic pain detection. Rigorous evaluation metrics, including sensitivity, specificity, and AUC-ROC, underscore the importance of quantitative insights into model performance. The work of Winslow, Brent & Kwasinski, Rebecca & Whirlow, Kyle & Mills, Emily & Hullfish, Jeffrey & Carroll, Meredith. (2022) [7], exemplifies a commitment to robust methodologies, emphasizing the necessity for standardized datasets and benchmarks to facilitate rigorous evaluation and comparison of methodologies. Continuous communication and interdisciplinary collaboration bridge the gap between technical aspects and real-world healthcare delivery, promoting a holistic approach to pain management. A forward-looking viewpoint is offered by Chen, J., Abbod, M., & Shieh, J. S. (2021) [10], who examine the complex interrelationship between pain and stress as well as the potentially revolutionary effects of wearable sensor-based health-monitoring systems. The integration of wearable sensors and cloud computing presents opportunities for customized healthcare solutions that tackle societal problems related to pain and stress management. Ahmed, I., Jeon, G., & Piccialli, F. (2021) [11], present a forward-looking approach, with extensions for capturing facial expressions and real-time interactive systems, reflecting a commitment to continuous improvement and broader applications in diverse healthcare scenarios. Their intelligent IoT-based system for automated patients' discomfort monitoring contributes to ongoing efforts to enhance patient care through innovative technological solutions. Werner, P., Lopez-Martinez, D., Walter, S., Al-Hamadi, A., Gruss, S., & Picard, R. W. (2019) [12], highlight the importance of focusing on specific physiological parameters, such as skin conductance fluctuations, in predicting severe pain in school-aged children after surgery. The call for more effort in advancing knowledge, gathering data, and demonstrating real-world usefulness signifies a commitment to translating research advancements into tangible improvements in clinical practice. In essence, the collective findings and methodologies presented in these studies underscore the dynamic nature of technology and healthcare research. The commitment to methodological rigor, interdisciplinary collaboration, and continuous improvement positions these contributions as valuable steps forward in the pursuit

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of more effective, accessible, and compassionate pain management in diverse healthcare settings. As technology continues to evolve, the potential impact of these innovations on improving pain management and patient care remains substantial, offering hope for addressing one of the most pervasive and subjective aspects of human experience.

# 4. Future Research Directions and Findings

The exploration of automated pain detection using machine learning represents a dynamic and evolving frontier that has opened new avenues for advancing healthcare technologies and enhancing patient outcomes. As we conclude our study, several promising areas for future research emerge, signaling the continuous evolution of this field.

Automated pain detection using machine learning is a rapidly evolving domain with tremendous potential. Future research endeavors should prioritize addressing the outlined areas to further augment the accuracy, applicability, and ethical considerations of automated pain detection systems. By embracing these challenges, researchers have the opportunity to contribute significantly to the ongoing transformation of healthcare practices & individuals experiencing pain. The synergy between machine learning and pain detection holds immense promise, and the identification and resolution of the outlined research areas will undoubtedly propel this field forward, fostering innovations that can positively impact patient care and well-being.

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# 23. Anomaly dependent intrusion detection framework for industrial internet of things

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# Abstract

The Internet of Things (IoT) represents an expansive network of interconnected smart devices, continuously growing in size and complexity. This network facilitates the exchange of information among devices, impacting various services and the daily activities of individuals. The efficacy and reliability of IoT are foundational to its integration into daily life, necessitating robust security measures to safeguard its operations. These measures are critical for ensuring secure communications, preventing unauthorized access or disruptions, and maintaining data confidentiality within sensor nodes through encryption. Consequently, there is a pressing need to enhance IoT network security to counteract potential vulnerabilities susceptible to exploitation by malicious entities. Despite the implementation of sophisticated encryption algorithms and security protocols, IoT networks remain vulnerable to cyber threats. Therefore, this paper introduces a Lightweight Intrusion Detection System designed to identify and mitigate specific cyber threats, notably the Hello Flood and Sybil attacks, within IoT networks.

Keyword: Internet of things, IDS, Security, WSN, 6LoWPAN, Hello Flood Attack, Sybil Attack.

# 1. Introduction

The Internet of Things (IoT) represents a complex network that links a variety of entities to the internet, allowing for the effortless exchange of information via established protocols. This connection provides unmatched data access and control over objects from any location at any time. Within an IoT environment, devices are wirelessly connected through small, smart sensors, enabling devices to communicate autonomously without the need for human interaction. IoT utilizes sophisticated communication techniques, facilitating device interactions and collaboration to create new applications and services. IoT is applied across numerous fields, including smart homes, intelligent urban infrastructure for improved city efficiency, health

monitoring, environmental protection, and effective water management. Yet, the expansion of IoT technology brings significant security challenges. The direct connection of IoT devices to the internet opens them up to various cyber threats, increasing the vulnerability of the network to attacks. Without strong security protocols, sensitive data could be at risk. Thus, it is critical to address these security weaknesses in the IoT architecture to protect data privacy and integrity (Chen, 2014).

#### 1.1 Intrusion Detection System

An Intrusion Detection System (IDS) plays a crucial role in monitoring and identifying malicious activities within a specific network or organization. It acts as an initial barrier to deter hackers and safeguard the system. An intrusion

refers to any unwanted or harmful activity that compromises the integrity of sensor nodes. An IDS can be either a software application or a hardware device, tasked with scrutinizing user and system behavior, recognizing patterns of known attacks, and detecting malicious activities within a group (Benabdessalem, 2014). It is engineered to oversee networks and nodes. pinpoint a range of disruptions within the organization, and notify users when such disturbances are detected. Serving primarily as a vigilant watcher or an alarm, the IDS intervenes by issuing alerts at the onset of an attack, thus preventing harm to the system infrastructure. It is capable of distinguishing between attacks originating from outside the network and those conducted by internal, possibly malicious or compromised nodes within the network. The IDS assesses the network packets to determine whether they originate from legitimate users or unauthorized intruders. Essentially, an IDS comprises three main components: monitoring, analysis, and alerting (Li, Shancang, 2015). The monitoring component keeps an eye on resource usage, traffic flow, and behavioral patterns. The analysis and detection component is vital for identifying disruptions based on predefined algorithms. Should any intrusion be detected, the alert component activates a warning signal, thereby initiating defensive measures (Sreeram, 2015).

# 1.2 Types of Intrusion Detection System

Intrusion Detection Systems (IDS) are security mechanisms designed to identify and mitigate unauthorized access or harmful activities within a system or network. These systems are broadly categorized into two types:

1. Host-Based Intrusion Detection System (HIDS): This system is implemented directly on individual computers or endpoints across the network. It scrutinizes the behavior and events occurring on the particular host for any indications of intrusion or unusual actions. HIDS is adept at catching attacks that are localized and specific to the host, such as alterations in the file system, unauthorized access attempts, and peculiar process activities. Due to its focused monitoring, it generally reports fewer false positives but might demand more resources because it functions at the host level. Notable examples of HIDS include OSSEC, Tripwire, and the Windows Security Center.

2. Network-Based Intrusion Detection System (NIDS): Positioned at crucial junctures within the network, especially at the periphery or significant segments, NIDS oversees the network's traffic flow in real-time. It evaluates packets and traffic patterns to pinpoint any abnormal or malicious behavior. NIDS excels in identifying attacks that affect multiple hosts or that move through the network, such as network reconnaissance (port scans), Distributed Denial of Service (DDoS) attacks, and the spread of malware. Given its analysis of extensive network traffic, it's more prone to raising false alarms. Prominent examples of NIDS tools are Snort, Suricata, and the Cisco IDS/IPS solutions.

Both HIDS and NIDS play pivotal roles in a comprehensive network security strategy, each with its specific focus areas, strengths, and potential limitations.

In addition to these two main types, there are variations and hybrid systems that combine elements of both HIDS and NIDS. These include:

- 3. Network Behavior Analysis (NBA): NBA systems focus on monitoring network traffic and identifying abnormal patterns of behavior. They establish a baseline of normal network behavior and raise alerts when deviations from the baseline occur. NBA systems can help detect unknown or zero-day attacks that traditional signature-based methods might miss.
- 4. Anomaly-Based IDS: Anomaly-based IDS, whether host-based or network-based, rely on identifying deviations from established baselines of normal behavior. They are effective at detecting previously unknown threats or zero-day attacks. However, they can generate false positives when legitimate activities deviate from the baseline.
- 5. **Signature-Based IDS:** Signature-based IDS rely on a database of known attack

patterns or signatures. They compare network traffic or system activities against these signatures and raise alerts when matches are found. Signature-based IDS are effective at detecting known threats but may miss new or evolving attacks.

- 6. Hybrid IDS: Hybrid IDS combines elements of both signature-based and anomaly-based detection. They can provide more comprehensive threat detection by leveraging known attack signatures and monitoring for unusual behavior. Hybrids aim to reduce false positives while maintaining strong security.
- 7. Distributed IDS (DIDS): DIDS involves deploying multiple IDS sensors across a distributed network. These sensors communicate with each other to share information and collectively analyze network traffic. DIDS can enhance detection accuracy and sca lability in large networks.

The choice of which type of IDS to use depends on the specific security requirements, the network architecture, and the resources available. Many organizations use a combination of HIDS and NIDS to provide comprehensive security coverage. Additionally, IDS can be integrated with Intrusion Prevention Systems (IPS) to not only detect but also actively block or mitigate threats.

# 2. Cyber Attacks on IOT Applications

Internet of Things (IoT) applications have become increasingly popular and are being integrated into various domains, ranging from smart homes and cities to industrial automation and healthcare. However, their widespread adoption has also made them a target for cyberattacks (Patel, Manish 2013).

Khan, K. R. "Review on Network Security and Cryptography." (2018). Here are some common cyberattacks on IoT applications:

1. Denial of Service (DoS) and Distributed Denial of Service (DDoS) Attacks: Attackers flood IoT devices or their network infrastructure with a massive volume of traffic, causing them to become overwhelmed and unavailable. These attacks disrupt the normal functioning of IoT devices and services, rendering them useless.

- 2. Botnets: Attackers compromise a large number of IoT devices to create a botnet, which can be used for various malicious purposes, including DDoS attacks, spam distribution, and cryptocurrency mining. Weak passwords and security vulnerabilities in IoT devices are often exploited to build botnets.
- 3. Man-in-the-Middle (MitM) Attacks: Attackers intercept and manipulate data traffic between IoT devices and their intended destinations. This can lead to data theft, unauthorized access, or the injection of malicious code or commands.
- 4. Device Spoofing and Cloning: Attackers impersonate legitimate IoT devices by cloning their identifiers or MAC addresses. This can allow attackers to gain unauthorized access to networks or services.
- 5. Eavesdropping and Data Interception: Attackers intercept and monitor data transmitted between IoT devices and the network. This can result in the theft of sensitive information or intellectual property.
- 6. Firmware and Software Exploits: Attackers target vulnerabilities in the firmware or software of IoT devices to gain unauthorized access or control. Failure to update and patch IoT device software can leave them vulnerable to known exploits.
- 7. Physical Attacks: Physical tampering with IoT devices can lead to unauthorized access or data theft. Attackers may physically compromise sensors, cameras, or other devices to gain access or manipulate data.
- 8. Ransomware Attacks: Some IoT devices, such as network-attached storage (NAS) devices or smart locks, may be targeted with ransomware attacks. Attackers encrypt the device's data or functionality and demand a ransom for its release.
- 9. Privacy Violations: IoT devices that collect personal data, such as smart home cameras and wearable devices, can be targeted for privacy breaches. Attackers may access or steal sensitive user information.
- 10. **Supply Chain Attacks:** Attackers compromise IoT devices at various points in the supply chain, including during

manufacturing or distribution. This can result in pre-installed malware or vulnerabilities in the devices.

To mitigate these cyberattacks on IoT applications, it is essential to implement strong security practices, including:

- Regularly updating and patching IoT device firmware and software.
- Using strong and unique passwords for IoT devices.
- Implementing network segmentation to isolate IoT devices from critical infrastructure.
- Employing intrusion detection and prevention systems (IDS/IPS).
- Conducting security assessments and vulnerability testing of IoT devices.
- Encrypting data in transit and at rest.
- Monitoring network traffic for unusual patterns.
- Educating users and administrators about IoT security best practices.

As the IoT landscape continues to evolve, staying vigilant and proactive in addressing security vulnerabilities is crucial to protecting IoT applications from cyber threats.

# 3. Literature Review

A survey of existing literature on intrusion detection systems (IDS) for the Internet of Things (IoT) uncovers an intensifying focus on fortifying the security framework of IoT environments. The summary below encapsulates the primary insights and developments within this arena:

- 1. **IoT Security Challenges:** The literature consistently underscores the distinct security hurdles inherent to IoT, such as the vast array of device types, limited resources, and varied communication standards. There's a consensus on the critical need for robust IDS solutions to safeguard IoT infrastructures.
- 2. Intrusion Detection System Varieties: Research delves into different IDS methodologies tailored for IoT, including anomaly detection, signature-based identification, and hybrid strategies. Anomaly detection employs statistical and machine learning techniques to spot irregularities in device communications. Signaturebased systems detect threats through

established patterns of malicious activities, while hybrid models aim to enhance detection precision by integrating both approaches.

- 3. Machine Learning in IDS: A considerable segment of research is dedicated to leveraging machine learning algorithms for detecting intrusions in IoT settings. Techniques such as Deep Learning, including CNNs and RNNs, are scrutinized for their proficiency in uncovering intricate patterns within IoT network data. The effectiveness of these methods often hinges on the careful selection of features and the reduction of data dimensionality to accommodate the constraints of IoT devices.
- 4. Approaches to Anomaly Detection: This category of IDS scrutinizes data traffic, device operations, or sensor outputs to pinpoint anomalies. Techniques like feature engineering, clustering, and statistical analysis are pivotal in recognizing deviations from established norms.
- 5. Signature-Based Detection Tactics: This approach utilizes databases of known threat signatures to identify attacks. The adaptation of threat intelligence feeds and the dynamic updating of signature databases are explored, with an acknowledgment of the challenges posed by false positives and novel (zero-day) threats.
- 6. Concerns Over Scalability and Efficiency: Given the typically limited processing capabilities and memory of IoT devices, the deployment of demanding IDS solutions is problematic. Research is therefore oriented towards developing lightweight detection methods and leveraging edge computing to alleviate the strain on device resources.
- 7. Network Segmentation Strategies: The division of IoT networks into separate, secure zones is advocated as a defensive strategy. Early detection of threats at the network's periphery is emphasized to prevent the spread of attacks within the IoT ecosystem.
- 8. **Response to Intrusions:** Beyond detection, the literature addresses the necessity for effective countermeasures, such as device quarantine, alerts, and the revision of security protocols. Automated responses,

including the blocking of hostile traffic or the isolation of affected devices, are considered.

- 9. Empirical Evidence and Case Studies: A portion of the studies present empirical findings and case analyses from IDS implementations in various domains like smart homes, healthcare, and industrial settings, providing a window into the operational challenges and the efficacy of IDS across diverse scenarios.
- 10. Calls for Standardization: There's an advocacy for standardized practices and frameworks for IoT intrusion detection to guarantee security consistency and compatibility across devices and systems.

In summary, the ongoing exploration in the realm of IoT IDS is characterized by a dynamic response to the escalating need for secure IoT networks, with researchers tackling the unique complexities of IoT security through innovative detection and response methodologies.

# 4. Proposed Method

The planned configuration for the Hi Surge and Sybil Assault locations is depicted in this part. All of the aforementioned methods are limited to flexible ad-hoc organisation. There are certain computational overhead limitations to those methods. These heavyweight techniques make them inappropriate for the IoT context. In the IoT organisation, there is no centralised method available to recognise Sybil and high surge attacks. We suggest a simple method to discover high surge assault and Sybil assault in an IoT organisation in order to get beyond these obstacles. In the IoT ecosystem, our suggested methodology is intended to distinguish between Hi surge assault and Sybil assault. For the IoT system's IDS scenario, we used a hybrid method. The IDS's engineering is shown in Figure 1, where every sensor hub is connected to the internet via an IPv6 border switch (6BR). The IDS framework's configuration uses a crossover method in which the centralised module on 6BR (GIDS) and the conveyed module (NIDS) on the sensor hubs collaborate to identify attacks. The diffused module identifies the Sybil assault and attacker, whereas the centralised module recognises the high surge assault. Module identifies the Sybil attack and attacker.



Figure-1: Architecture of IDS

#### 4.1 Proposed Algorithm



Figure 2: Figure of Proposed Work.

The algorithm proposed in the study is presented in Figure 2.

**Data Collection:** The first process of this work is to collect IoT attack dataset from various source. We have found some datasets we have collected is described later in this survey.

- Data Pre-processing: The next process is Data pre-processing which mainly deals with the cleaning of data, the abstraction of features, vectorization and visualization of features. The goal of this steps to create vectors from the data.
- Testing and Tranning Data Splitting: After vectorization step completes our next goal is to split the data into 70-30 and 80-20 ratio into training-test set. The training-test set is then used as an input for Learning Algorithm i.e., SVM, ANN, Logistic Regression, LOF etc.
- Model Evaluation: The models are generated from the various algorithm using IoT attack datasets and final models are selected for evaluation. The models evaluated by the standard statistical evaluation matric and performance of proposed models are compared.

# 5. Conclusions

The Internet of Things is a clever organisation that connects real-world items to the internet so they can communicate. IoT development has given rise to a vast array of problems. We come to the conclusion that security concerns around the Internet of Things cannot be ignored. We learn about various security breaches and how they influence IoT applications. In related study, we discovered several IDS techniques to differentiate those assaults. These methods have several limitations, such as the need for greater computing resources to locate attacks and the absence of a centralized process for assault identification. In the IoT setup, there is no method available to distinguish between Hi surge and Sybil assault. We trust our proposed arrangement will incredibly offer assistance to identifying flood attack and Sybil assault in IoT. Here we are attempting to give a solution which can include more security to the IoT organize. In future we are going execute the proposed strategy in Contiki OS with Coojatestsystem. In future we will implement the proposed method in Contiki OS with Cooja simulator. We are confident that our suggested arrangement will significantly help to spot hi flood attack and Sybil assault in IoT. Here, we're striving to offer a solution that will give the IoT organisation better security. In the future, using the Cooja test system and Contiki OS, we will implement the suggested technique. In the future, we'll use the Cooja simulator along with Contiki OS to accomplish the suggested approach.

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# 24. Face recognition and detection

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#### Abstract

Face recognition has gained a lot of traction because of its numerous applications in a variety of industries, such as smart cards, surveillance, law enforcement, entertainment, and information security. It is a crucial subject in pattern recognition, computer vision, and image processing. Features can be extracted using two primary methods: appearance-based and model-based. Appearance-based methods identify faces using global representations. The creation of a human face model that accurately represents facial diversity is the aim of model-based face methods. The similarity between two photos is indicated by the separation between their vectors.

Keywords: Face detection, Face recognition, Facial Images, Eigenfaces, OpenCV.

# 1. Introduction

Face recognition is a technique that uses a person's unique face to identify them as an individual. Its function goes beyond simple technological innovation; it offers a potent tool with consequences for accessibility, security, and personalization. Face recognition software can be used to recognize individuals in real time or in images. The most effective technique for facial recognition in deep learning is the one that uses OpenCV and Python for facial recognition.

The anatomy of the human face is incredibly dynamic and complicated, and its features can change drastically and fast over time. There are many different actions from all facets of human life that go into face recognition. Face recognition is a skill that humans possess, but because memorising too many faces may be challenging, machine learning is now being enhanced to do this function. When creating or developing face recognition systems, scientists make an effort to comprehend the structure of the human face.

Researchers can better grasp the fundamental system by studying the approach of the facial recognition system in humans. A technique for recognizing faces in humans may use information from some or all of the senses, including vision, hearing, and touch. To memorise and store faces, each of these pieces of information is either employed alone or together. In many instances, the environment the person is in plays a role in a human face recognition system. A machine recognition system has difficulty managing and merging large amounts of data. However, it might be challenging to remember several faces. The memory capacity of a computer system is a key benefit. The study of human characteristics that might be exploited for facial recognition is ongoing. For face recognition, local and global characteristics are required.

# 2. Related Works

Face recognition is a vast field with a rich history of research and development. Many significant works, studies, and breakthroughs have contributed to the advancement of face recognition technology. Here are some notable related works and milestones in the field of face recognition:

1. Eigenfaces (1991): The Eigenfaces algorithm, proposed by Matthew Turk and Alex Pentland, was one of the pioneering works in face recognition. It introduced the concept of using principal component analysis (PCA) for facial feature extraction, significantly influencing subsequent research.
- 2. LBPH (Local Binary Pattern Histogram) (1994): Local Binary Pattern Histogram, introduced by T. Ojala, M. Pietikäinen, and T. Mäenpää, is a texture-based face recognition method. LBPH has been widely used for its simplicity and robustness to variations in lighting and expression.
- 3. Viola-Jones Face Detection Framework (2001): Paul Viola and Michael Jones proposed a real-time face detection framework that became a fundamental component of many face recognition systems. Their work focused on fast and accurate face detection using Haar-like features and AdaBoost classifiers.
- 4. DeepFace (2014): Facebook's DeepFace, developed by Yaniv Taigman and colleagues, showcased the power of deep learning in face recognition. It introduced a deep convolutional neural network (CNN) that achieved near-human performance in face verification tasks.
- 5. FaceNet (2015): Google's FaceNet, developed by researchers at Google Research, is another influential work in deep learning-based face recognition. It introduced the concept of learning face embeddings directly in a high-dimensional space, enabling accurate face recognition with deep neural networks.
- 6. VGGFace (2015): VGGFace, developed by researchers at the University of Oxford, is a deep learning model for face recognition. It demonstrated the effectiveness of pre-trained CNNs in recognizing faces across a wide range of variations.
- 7. DeepID (2014): DeepID, developed by researchers at the Chinese University of Hong Kong, proposed a deep neural network architecture for face verification and identification tasks. It attained cutting-edge outcomes in standards for facial recognition.
- 8. ArcFace (2019): ArcFace, introduced by Deng et al., improved face recognition accuracy by introducing a margin-based loss function. This work contributed to achieving high accuracy in unconstrained face recognition scenarios.

- 9. Bias and Fairness Studies: Researchers have conducted studies highlighting the biases and fairness issues in face recognition algorithms, raising awareness about the need for more equitable technology.
- 10. 1One-shot and Few-shot Learning: Advances in one-shot and few-shot learning techniques have enabled face recognition with limited training data, making it more practical for real-world applications.
- 11. **Privacy-Preserving Face Recognition:** Researchers have also worked on privacy-preserving face recognition techniques, such as secure multiparty computation and homomorphic encryption, to protect individuals' privacy.
- 12. **Real-world Applications:** The use of facial recognition in a variety of fields, such as security, surveillance, access control, healthcare, and human-computer interaction, has been the subject of numerous studies.

These are just a few examples of significant works and trends in face recognition. The field continues to evolve with ongoing research in deep learning, fairness, privacy, and real-world applications, contributing to the development of more robust and ethical face recognition systems.

# 3. Performance Evaluation Metrics in Face Recognition

- 1. To determine the accuracy and efficacy of face recognition systems, performance evaluation is crucial. A number of measures are frequently employed to assess these systems' performance. These criteria make it easier for researchers and developers to assess the effectiveness of facial recognition software and pinpoint areas in need of development. The following are some important measures for performance evaluation in facial recognition:
- 2. Accuracy: Accuracy is a fundamental metric that measures the overall correctness of a face recognition system. It calculates the percentage of correctly identified faces out of the total number of faces. Formula: Accuracy = (Number of Correct

Recognitions / Total Number of Faces) \* 100% While accuracy provides an overall measure of performance, it may not capture imbalances in the dataset or distinguish between false positives and false negatives.

- 3. False Positive Rate (FPR): Measures the rate at which the system incorrectly identifies non-matching faces as matches (false alarms).Formula: FPR = (Number of False Positives / Total Number of Non-Matching Faces) \* 100%A lower FPR indicates a better system in terms of security and privacy.
- False Negative Rate (FNR): FNR measures the rate at which the system fails to correctly identify matching faces (misses).Formula: FNR = (Number of False Negatives / Total Number of Matching Faces) \* 100%Reducing the FNR is critical for improving system reliability.
- True Positive Rate (TPR) or Sensitivity: TPR, also known as sensitivity or recall, measures the rate at which the system correctly identifies matching faces. Formula: TPR = (Number of True Positives / Total Number of Matching Faces) \* 100%A high TPR indicates that the system is effective at recognizing genuine matches.
- 6. Precision: Precision measures the accuracy of positive predictions by expressing the percentage of correctly identified matches among all positive predictions. The formula for precision is as follows:
  \* 100% / (Total Number of Positives / (Total Number of Positives + Total Number of False Positives))Accuracy is essential when lowering false alarms is the aim.
- 7. F1 Score: The harmonic mean of recall and precision (TPR) is the F1 score. It offers a fair assessment of a system's effectiveness, especially when the dataset's proportion of matching and non-matching faces is unbalanced.F1 Score is calculated as follows: 2 \* (Precision \* TPR) / (Precision + TPR).
- 8. Receiver Operating Characteristic (ROC) Curve: A graphical illustration of the trade-off between TPR (sensitivity) and FPR for various decision thresholds is the ROC curve. AUC-ROC, or the area under

the ROC curve, offers a concise assessment of the overall performance of the system.

- 9. Precision-Recall (PR) Curve: For various judgment thresholds, the PR curve illustrates the trade-off between recall and precision. For unbalanced datasets, the area under the PR curve (AUC-PR) is a helpful statistic.
- 10. 1Rank-1 Accuracy: Rank-1 accuracy measures whether the top-ranked match in a list of candidates is the correct match. It is commonly used in one-to-many identification scenarios.
- 11. 1Mean Average Precision (mAP): mAP is a metric used for ranking-based retrieval systems, such as searching a database for the most similar faces. It considers both precision and recall over a range of retrieval ranks and provides an average precision score.

The choice of performance metrics depends on the specific application and the goals of the face recognition system. Different applications may prioritize different metrics. For example, in security applications, minimizing the false positive rate may be crucial, while in a user authentication scenario, achieving a high true positive rate may be the primary objective. Researchers and developers often use a combination of these metrics to comprehensively evaluate the performance of a face recognition system.

# 4. Variations in Facial Images

Facial images exhibit significant variations due to various factors, and these variations can pose challenges for face recognition systems. Understanding and accounting for these variations is crucial for building robust and accurate face recognition algorithms. Here are some common variations in facial images:

1. Pose Variation: Pose refers to the orientation of the face relative to the camera. Faces can be captured in various poses, such as frontal, profile, or tilted. Extreme pose variations can make it challenging to recognize faces, as the facial features appear differently in each pose. Advanced face recognition algorithms use 3D modeling or pose estimation to handle pose variations.

- 2. Illumination Changes: Lighting conditions have a significant impact on facial appearance. Illumination variations can result in shadows, highlights, and changes in skin tone, making it difficult to match faces. Some face recognition algorithms employ normalization techniques to reduce the effects of illumination changes.
- 3. Expression Changes: Facial expressions can change the shape of the face, including the position of the eyes, mouth, and facial muscles. Recognizing faces across different expressions (e.g., smiling, frowning, neutral) is a challenging task. Some systems use expression-invariant feature extraction or facial landmark tracking to address this issue.
- 4. Aging: Facial appearance naturally changes over time due to aging. Recognizing individuals across different age groups can be challenging, especially for longterm applications. Some face recognition systems incorporate age-related features or utilize deep learning models trained on diverse age groups.
- 5. Facial Hair and Accessories: The presence of facial hair, glasses, hats, or other accessories can alter the appearance of a face. Some recognition systems need to account for these variations, such as by detecting and recognizing faces with and without glasses separately.
- 6. Resolution and Image Quality: Lowresolution images or images with poor quality, such as those from surveillance cameras, can impact recognition accuracy. Noise, compression artifacts, and blurriness can hinder feature extraction and matching.
- 7. Occlusions: Facial features may be partially or completely occluded by objects, other people, or the person's own hands. Handling occlusions is important in scenarios like surveillance and security.
- 8. Race and Ethnicity: Face recognition algorithms can be sensitive to race and ethnicity, potentially leading to biased or inaccurate results. Diverse and representative training data can help mitigate these biases.
- 9. Gender: Gender differences in facial features, such as hair length and facial hair, can affect recognition accuracy.

Gender-invariant feature extraction methods may be employed.

10. Facial Makeup: Makeup, including cosmetics like lipstick and eyeshadow, can alter the appearance of a face. Some recognition systems consider makeup variations, while others may have difficulty recognizing individuals with heavy makeup.

Addressing these variations often requires a combination of techniques, including data augmentation, robust feature extraction methods, advanced machine learning models, and careful preprocessing. Moreover, it's important for developers and researchers to continuously evaluate and improve face recognition systems to handle real-world variations effectively while maintaining fairness, accuracy, and privacy.

# 5. Face Recognition Algorithms

The technology that allows computers to recognize and verify people based on their facial traits is based on face recognition algorithms. Numerous face recognition algorithms have been created over time, each with a unique methodology and degree of accuracy. The following are a few well-known face recognition algorithms:

Eigenfaces: One of the first facial recognition algorithms is called Eigenfaces, and it uses principal component analysis (PCA). By representing faces as linear combinations of eigenfaces—that is, eigenvectors of the covariance matrix of the training data it lowers the dimensionality of facial data. Faces can be projected onto a lower-dimensional space using eigenfaces for:

- 1. Fisherfaces (Linear Discriminant Analysis - LDA): F isherfaces, also known as LDA, aim to maximize the separation between classes (different individuals) while minimizing variation within each class. It focuses on preserving the discriminatory information in the data. Fisherfaces can perform better than Eigenfaces in scenarios with variations in lighting and expression.
- 2. Local Binary Pattern Histogram (LBPH): A texture-based face recognition method is called LBPH. It functions by segmenting the face into smaller areas and uses local binary patterns to examine each

region's texture pattern. These patterns' histograms are employed in classification. Although LBPH can withstand changes in lighting, it could not adapt well to changes in posture.

- 3. Viola-Jones Algorithm: The Viola-Jones algorithm is primarily used for face detection but can be used for face recognition as well. It employs Haar-like features and AdaBoost classifiers to detect faces quickly. Once faces are detected, other recognition methods can be applied.
- 4. Deep Learning-Based Approaches: Deep learning, particularly Convolutional Neural Networks (CNNs), has revolutionized face recognition. Models like FaceNet, VGGFace, and DeepFace utilize deep CNN architectures to directly learn feature representations from facial images. These models can handle variations in pose, lighting, and expression, achieving high accuracy in face recognition tasks.
- 5. Deep Metric Learning: Deep metric learning approaches aim to learn embeddings of faces into a feature space where distances between face embeddings directly correspond to face similar it Triplet loss and contrastive loss are commonly used techniques for training such models. Siamese networks and triplet networks are popular architectures for deep metric learning.
- 6. Hybrid Approaches: Some systems combine traditional techniques like Eigenfaces or LBPH with deep learning methods to leverage the strengths of both. For example, a deep neural network may be used to extract features, and then a traditional classifier is employed for recognition.
- 7. One and Few shot Learning: These approaches are designed to recognize faces with very few training examples or even just one image. Siamese networks and prototype networks are two techniques used in one-shot and few-shot face recognition, respectively.

The particular application, the training data that is available, the computational resources available, and the required accuracy level all influence the choice of face recognition algorithm. Deep learning-based methods are the method of choice for many contemporary applications since they have substantially improved the state of the art in face recognition. But in some situations, conventional techniques like Eigenfaces and LDA might still be helpful.

#### 5.1 Simulation

At first Create a Python script to simulate the face recognition process using the trained model using OpenCV Execute my Python script to run the simulation. It should detect and label faces in the provided image. In this project I used OpenCV package first install this package and then, enter in Python interpreter and that will be 3.5 (or above) version. Inside the interpreter import the OpenCV library then Testing the Camera and create a python code to run and after that the face will be captured and detect and at the last we get result.

Facial recognition is a biometric technique that uses facial feature analysis and comparison to identify and authenticate people. It is a branch of computer vision and pattern recognition that has drawn a lot of interest and is being used in a number of areas, such as personal device identification, security, surveillance, and human-computer interaction.

Here is an introduction to the key aspects of face recognition:

- 1. Biometric Identification: Face recognition is a biometric modality, which means it uses unique physical or behavioral characteristics to distinguish individuals. In this case, it relies on the distinct features of a person's face, such as the arrangement of eyes, nose, mouth, and other facial landmarks.
- 2. Data Acquisition: To perform face recognition, you need an image or video of a person's face. This data can be collected through various means, including cameras, webcams, or even existing photos and videos.
- 3. Feature Extraction: Once the facial data is collected, the system extracts key features from the face, such as the distances between facial landmarks, the shape of the nose, the size of the eyes, and other unique characteristics. These features are often converted into a mathematical representation for analysis.
- 4. Face Detection: Before recognizing a face, the system must locate the face within

the image or video frame. Face detection algorithms are used to identify the region of interest (ROI) containing the face.

- 5. Face Recognition Algorithms: There are several approaches to face recognition, including:
  - Eigenfaces: Using principal component analysis (PCA) to extract and compare facial features.
  - LBPH (Local Binary Pattern Histogram): A texture-based method that focuses on local facial patterns.
  - Deep Learning: Face recognition has been transformed by convolutional neural networks (CNNs). Models like VGGFace, FaceNet, and deep learning frameworks like TensorFlow and PyTorch are widely used for this purpose.
- 6. Training and Testing: In order to recognize faces, the system needs to be trained on a dataset of known faces. During training, it learns to distinguish the unique facial features of each individual. After training, it can be tested on new, unseen faces to verify or identify individuals.
- 7. Applications:
  - Security and Surveillance: Face recognition is used in access control systems, border security, and surveillance to identify and track individuals.
  - User Authentication: Many smartphones and devices use face recognition for user authentication, allowing users to unlock their devices or apps by simply looking at the camera.
  - **Retail and Marketing:** Some retailers use face recognition to analyze customer demographics and shopping behaviors.
  - Law Enforcement: Police departments may use face recognition to identify suspects from surveillance footage or mugshot databases.
- 8. Challenges and Concerns: Face recognition technology raises several ethical and privacy concerns, including issues related to surveillance, data security, and potential biases in algorithms. Ensuring the responsible and ethical use of this technology is a significant challenge.

In summary, facial recognition technology is strong and has many uses, but its implementation needs to be carefully studied and regulated to handle ethical and privacy issues. Deep learning developments have greatly increased facial recognition systems' accuracy and dependability, making them a crucial component of contemporary technology and security solutions.

# 6. Conclusion

Over the past 20 years, facial recognition technology has made considerable advancements. Identification data can now be automatically verified for tracking, secure transactions, security requirements, and building access control. These systems usually work in controlled environments, and in order to attain high recognition accuracy, recognition algorithms may modify environmental constraints. But the next wave of facial recognition technology will be used extensively in smart environments where robots and computers act more like helpful assistants.

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# 25. A brief introduction to elimination of noise from big data in social media context: A review

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#### Abstract

This article aims to comprehend the idea of the noise of big data, as well as the consequences of the types and sources of it in social media; primarily focuses on some of the current methods, techniques and approaches for the elimination of noise from social media big data and seek to identify new ideas and approaches for the same. These approaches' strengths, limitations and comparative analysis are discussed, providing insights into their applicability and effectiveness. Here, the body of literature forming the present investigation's basis was evaluated. An analysis of related literature sheds light on research efforts. The enormous growth of social media platforms has led to an unprecedented volume of user-generated content which brings with it various challenges, particularly in the form of noise. Noise refers to irrelevant, erroneous, or spam-like information that hampers the quality and reliability of the data. This paper provides a concise introduction to the elimination of noise from big data and possible challenges posed by various factors in the context of social media. It comprehensively reviews existing research and methodologies employed to mitigate noise and enhance data quality in this domain. The paper also highlights the impact of noise on various applications, such as sentiment analysis, information retrieval, and trend detection, underscoring the need for effective noise elimination strategies. Additionally, the paper discusses the emerging trends and future directions in noise elimination from big data in social media. It explores the potential of advanced technologies like deep learning, data fusion, and social network analysis to further enhance noise reduction efforts. By summarizing existing methodologies and highlighting future prospects, it provides a valuable resource for those seeking to improve data quality and extract meaningful insights from social media platforms.

Keywords: Noise Reduction, Big Data, Social Media, Data Cleaning, Data Preprocessing.

#### 1. Introduction and Background

We live in an interactive societal world where people constantly communicate with each other. Social media-based platforms produce large amounts of relational and non-relational data in a brief period (Rahman and Reza 2021) (Rahman and Reza 2022). An average Internet user uses up and shares a massive amount of digital content each day through widespread social online services such as Facebook, Twitter, YouTube, Instagram and SnapChat, LinkedIn, blogs, WhatsApp, Instagram, Pinterest,etc (Olshannikova et al. 2017) (Matilda S. 2017). As per the DataReportal overview, social media growth has steadily increased in a greater part of the world i.e. 4.76 billion people are now engaged in social media usage (59%), 137 million new users have logged in to an Internet communication system within the last 12 months and the average daily social media consumption time is 2h 31m (Chaffey 2024). Social media has evolved into a prolific data repository, fueled by billions of users who generate extensive content on a day-to-day basis. This vast repository of data has garnered significant attention across diverse domains, including sentiment analysis, trend detection, marketing research and crisis management. The sheer volume of data pertaining to digital social interactions has contributed to the widespread adoption of social media and computer-mediated communication. It embraces diverse modes of communication, such as textual exchanges, entertainment content, self-representation videos, news dissemination and other user-generated social media content from third-party sources. However, this rapid generation and storage of abundant social data, commonly referred to as Big Social Data (BSD), presents significant challenges due to the presence of noise (Olshannikova et al. 2017). At first, social media data should be discovered, collected and prepared by removing unnecessary or irrelevant information and after that they can be analyzed to precisely measure diverse interactive and behavioral patterns of social media users.

Noise in social media data refers to irrelevant. erroneous, distorted, meaningless or spam-like information that obscures the quality and reliability of the underlying data. In the context of data science and machine learning, noise refers to random or irrelevant information that can interfere with the interpretation of data. It can also refer to the overwhelming number of notifications and updates that a user may receive, making it difficult to find important information among the clutter. It can arise from various sources, including typographical errors, automated bot activity, intentional misinformation and the enormous volume and diversity of user-generated content. The prevalence of noise poses a considerable obstacle to extracting meaningful insights and accurate analysis from social media big data. Noise can make it more difficult for machine learning algorithms to accurately identify and learn from the true patterns in the data, leading to less accurate models and predictions.

Here are some examples of noisy big data in social media (Kim, Huang, and Emery 2017; "What Is Noise in Data Mining - Javatpoint," n.d.; Waldherr et al. 2016; "Signal to Noise Ratio, Marketing, and Communication," n.d.):

1. Spam and Fake Accounts: Social media platforms are often plagued by spam accounts and fake profiles that generate irrelevant, misleading, or malicious content. These accounts may engage in activities such as posting repetitive or irrelevant information, spreading misinformation, or promoting scams. Identifying and filtering out these noisy accounts and their content is crucial to maintaining data quality.

- 2. Irrelevant or Off-Topic Posts: Social media users often post content that may be irrelevant or off-topic to a particular discussion or thread. This noise can make it challenging to extract relevant information or sentiment analysis accurately.
- 3. Typos and Abbreviations: Social media posts are frequently characterized by informal language, abbreviations and typographical errors. These linguistic nuances can introduce noise when processing the text data, affecting tasks such as sentiment analysis, text classification, or topic modeling.
- 4. Emojis and Emoticons: Social media users extensively use emojis and emoticons to express emotions or convey messages. However, interpreting and analyzing these graphical symbols can be challenging, as their meanings may vary across cultures, contexts, or individuals. Noise can arise when attempting to extract sentiment or analyze textual data containing emojis.
- 5. Sarcasm and Irony: Social media platforms are breeding grounds for sarcasm and irony, which can add complexity to sentiment analysis or natural language processing tasks. Deciphering and accurately comprehending sarcastic or ironic statements poses a considerable hurdle owing to the intricacies inherent in language and context.
- 6. Duplicate and Repetitive Content: On social media, users often share or repost content, resulting in duplicates or repetitive posts across different accounts or timeframes. This redundancy can lead to noise when analyzing data, as it may skew statistics or misrepresent trends.
- 7. Noisy User Interactions: Social media platforms facilitate interactions between users through comments, replies, mentions, or shares. However, these interactions can be noisy due to spam comments, off-topic discussions, or abusive behavior. Filtering out irrelevant or malicious user interactions is necessary to obtain meaningful findings derived from social media data.

- 8. Data Inconsistencies: Social media data can suffer from inconsistencies, such as missing information, contradictory statements, or conflicting timestamps. These inconsistencies can introduce noise and impinge the correctness of data analysis or modeling.
- 9. Overwhelming Notifications: Social media platforms often send notifications to users for various activities, such as likes, comments and mentions. When these notifications become excessive or irrelevant, they can contribute to noise and distract users from important or meaningful interactions.
- 10. 1Trolling and Online Harassment: Trolling involves the deliberate act of inciting or tormenting others in online settings. This behavior entails activities such as posting offensive or derogatory remarks, launching personal attacks, or disseminating hate speech. The consequences of trolling and online harassment manifest in the form of a detrimental and disruptive atmosphere, generating negativity on social media platforms.
- 11. Fake News: Fake news refers to intentionally false or misleading information presented as factual news. This can include fabricated stories, manipulated images or videos, or misleading headlines. Fake news can spread rapidly on social media platforms, contributing to misinformation and noise.
- 12. Echo Chambers and Polarization: Social media platforms can foster echo chambers, where individuals are exposed to content and opinions that align with their existing beliefs. This can lead to a lack of diverse perspectives, reinforcing biases and contributing to polarization. Echo chambers can create a noisy environment where meaningful dialogue and understanding are hindered.
- 13. Cyberbullying: It refers to the use of digital communication platforms, such as social media, to harass, intimidate, or harm individuals. It involves the deliberate and repeated targeting of individuals through various forms of aggressive behavior, including sending abusive messages, spreading rumors, sharing

embarrassing content, or engaging in online harassment campaigns.

Addressing these sources of noise in social media big data requires robust data preprocessing techniques, such as spam detection, sentiment analysis, text normalization and data deduplication. Additionally, advanced natural language processing algorithms and machine learning models, sentiment analysis, spam detection and crowd-based filtering methods can help mitigate the impact of noise and improve the quality of insights derived from social media data. The strengths, limitations and comparative analysis of these approaches are discussed and insights into their effectiveness and applicability are provided.

In addition to the current state of noise elimination techniques, the review will also explore emerging trends and future directions in this field. It will discuss the potential of advanced technologies such as deep learning, data fusion and social network analysis to further enhance noise reduction efforts and improve the quality of social media big data analysis.

By consolidating existing knowledge and insights, this review aims to equip researchers and practitioners with a foundational understanding of the challenges associated with noise elimination in connection with social media big data. It will serve as a valuable resource for those seeking to improve data quality, enhance analysis accuracy and derive meaningful insights from the vast amount of information available on social media platforms.



The consequences of noise on social media (Pampapura Madali, Alsaid, and Hawamdeh 2022; Zimmerman 2022) The consequences of noise on social media can be significant and have several negative effects:

- 1. Information Overload: The sheer volume of content on social media platforms can overwhelm users, making it difficult to filter through the noise and find relevant and accurate information. This can lead to information overload and cognitive overwhelm, causing users to feel stressed, anxious and fatigued.
- 2. Spread of Misinformation: Noise on social media often includes the spread of misinformation, fake news and rumors. These false or misleading pieces of information can be rapidly shared and amplified, leading to a distorted understanding of events and issues. This can result in significant repercussions, such as influencing public opinion, shaping political narratives and undermining trust in institutions.
- 3. Reduced Trust and Credibility: The prevalence of noise on social media can erode trust in the platform itself and in the information shared on it. When users encounter an extensive irrelevant or false content, they may become skeptical of the reliability and credibility of the information they come across. This can induce a general distrust of social media platforms and reluctance to engage with them.
- 4. Echo Chambers and Polarization: The presence of noise on social media platforms can foster the creation of echo chambers, wherein individuals are predominantly exposed to information and viewpoints that align with their preexisting beliefs and values. This can give rise to a reinforcement of existing biases and a reduced exposure to diverse perspectives, resulting in increased polarization and a lack of constructive dialogue.
- 5. Impacts on Mental Health: The constant exposure to noise on social media, including negative or toxic content, can have detrimental effects on mental health. It can contribute to feelings of anxiety, depression, loneliness and low self-esteem. The comparison culture and online harassment prevalent on social media platforms can further exacerbate these issues.

6. Time and Productivity Drain: The abundance of noise on social media can consume significant amounts of users' time and attention. Constantly scrolling through irrelevant content and engaging in unproductive discussions can detract from more meaningful activities and reduce overall productivity.

To mitigate the consequences of noise on social media, it is crucial for users to exercise discernment when assessing the information they come across, verify sources and engage in responsible sharing and consumption of content. Social media platforms can also play a role by implementing measures to combat misinformation, reduce spam and provide users with better tools to filter and personalize their content feeds.

Impact of Noise on Data Analysis (Rao, P Srinivasa 2018; Xiong et al. 2006)

- 1. Skewed Insights: Noise in social media big data can introduce biases and distort the patterns and trends within the data. It can lead to inaccurate analysis and misleading insights, as the presence of noise can overshadow the true signals present in the data. For example, if a sentiment analysis model is trained on noisy data that contains a significant amount of spam or irrelevant content, the resulting sentiment scores may not accurately reflect the actual sentiment of users, leading to skewed insights and decision-making.
- 2. Reduced Data Quality: Noise compromises the overall quality and reliability of the dataset. Irrelevant or spam-like content can dilute meaningful information and introduce errors and inconsistencies. This reduces the trustworthiness of the data and makes it challenging to draw accurate conclusions. Noise can also result in missing or incorrect data, further degrading the overall quality and integrity of the dataset.
- 3. Time and Resource Consumption: Analyzing noise-ridden data requires additional time and resources, which can impact the efficiency and productivity of data analysis tasks. Noise elimination involves preprocessing steps, such as data cleaning, filtering and classification, which require computational resources and manual effort. The proximity of

noise prolongs the data analysis process, as analysts need to invest extra effort in identifying and removing noise before performing meaningful analysis. This can delay decision-making processes and hinder timely insights extraction from the data.

- 4. Increased Complexity: Noise can increase the complexity of data analysis tasks. Analysts need to develop and implement sophisticated algorithms and techniques to distinguish between signal and noise. This adds complexity to the data analysis pipeline and increases the computational burden. Furthermore, the existence of noise can introduce uncertainties and complexities when it comes to modeling and predictive tasks, as the presence of noise can disrupt the underlying patterns and relationships within the data, thereby posing challenges to accurate modeling and prediction.
- 5. Negative Impact on Decision-Making: The presence of noise in social media big data can have a detrimental impact on decision-making processes. Decision-makers rely on accurate and reliable insights derived from data analysis to inform their strategies and actions. However, if the data is contaminated with noise, the decisions made based on flawed or misleading insights can be suboptimal or even detrimental to the organization's goals.

Effectively addressing noise in social media big data is crucial to mitigate these impacts and ensure that data analysis efforts yield accurate, reliable and valuable insights. By employing robust noise elimination techniques, organizations can enhance the quality of their data and make more informed decisions based on reliable insights.

# 2. Methodologies and Techniques for Noise Elimination

1. Machine Learning Algorithms: Machine learning algorithms can be utilized for noise detection and classification. Supervised learning algorithms can be trained on labeled data to identify and classify noise patterns. Unsupervised learning algorithms can also be employed to detect anomalies or patterns that deviate from the norm, which may indicate the presence of noise. These algorithms can learn from historical data and leverage statistical techniques to identify and eliminate noise in social media big data.

Noise can have several negative effects influencing the effectiveness of machine learning models (Nazari et al. 2018; Saseendran et al. 2019; Caiafa et al. 2021):

- 1. Reduced Accuracy: Noise has the potential to introduce unpredictable fluctuations within the data, thereby complicating the task of machine learning models in accurately identifying the genuine underlying patterns. This can lead to less accurate predictions and lower overall model performance.
- 2. Overfitting: When noise is present in the training data, machine learning models may attempt to incorporate both the noise and the underlying patterns. As a consequence, overfitting can occur, wherein the model becomes excessively tailored to the training data and exhibits subpar performance when confronted with new, unseen data. Overfitting can lead to poor generalization and decreased model performance.
- 3. Increased Complexity: Noise can add complexity to the data and make it more difficult for machine learning models to learn meaningful patterns. Models may need to incorporate additional parameters or structures to account for the noise, increasing the complexity and potentially leading to overfitting.
- 4. Misleading Insights: Noise can distort or obscure the true relationships between variables in the data. This may result in erroneous conclusions and misinterpretations of the data, potentially impacting decision-making outcomes derived from the model's results.

To minimize the influence of noise, data preprocessing techniques such as data cleaning, outlier removal and feature selection can be applied. Additionally, using robust machine learning algorithms that are less sensitive to noise, such as ensemble methods or regularization techniques, can help improve model performance in the propinquity of noise.

- 2. Natural Language Processing (NLP) Techniques: NLP techniques play a vital role in noise elimination by analyzing text content. Sentiment analysis techniques can determine the sentiment polarity of social media posts, enabling the identification and filtering of noise based on negative or irrelevant sentiments. Partof-speech tagging methods can aid in the identification and elimination of extraneous words or irrelevant linguistic elements. Named entity recognition techniques can be utilized for identification and removal of noise related to irrelevant entities or topics (Al Sharou et al. 2021).
- 3. Sentiment Analysis and Spam Detection: Sentiment analysis techniques can be applied to social media data to identify and filter out noise. By determining the sentiment expressed in posts or comments, sentiment analysis models can identify spam-like or irrelevant content and classify it as noise. Spam detection algorithms, such as machine learning-based classifiers or rule-based approaches, can be employed to identify and remove spam content, including promotional messages, irrelevant advertisements, or bot-generated content (Dipti Shama et al. 2020).

Improving sentiment analysis techniques to better handle the challenges of noise reduction in social media big data requires continuous research and development. Here are some ways sentiment analysis techniques can be enhanced (Alsayat, 2022):

- 1. Contextual Understanding: Developing models that can better capture contextual information is crucial. Techniques like contextual embeddings, attention mechanisms and contextual language models (e.g., BERT, GPT) can help improve the understanding of language nuances, sarcasm and cultural references. Training models on diverse and context-rich datasets can enhance their ability to handle context effectively.
- 2. Multilingual Support: Investing in research and resources to improve sentiment analysis for multilingual data is essential. This involves training models on diverse language datasets, considering

language-specific characteristics and leveraging transfer learning approaches to generalize sentiment analysis across languages. Adapting models to handle code-switching and dialect variations can also improve performance.

- 3. Emotion Detection: Expanding sentiment analysis models to include a broader range of emotions can enhance noise reduction efforts. Developing models that can detect and classify complex emotional states can provide a more nuanced understanding of sentiment in social media data. Integrating techniques from affective computing and psychology can help improve emotion detection capabilities (Jim et al. 2024).
- 4. Robust Training Data: Ensuring high-quality and diverse training data is essential for improving sentiment analysis models. Efforts should be made to address biases in training data and create balanced datasets that represent diverse perspectives and sentiments. Incorporating user feedback and crowdsourcing annotations can help improve the quality and representativeness of training data.
- 5. Personalization and User Preferences: Advancing sentiment analysis models to consider individual preferences and personalized understanding of sentiment can enhance noise reduction efforts. Developing techniques that can adapt to user feedback, user profiles and historical interactions can help tailor sentiment analysis to individual users, reducing noise according to their preferences.
- 6. Handling Short and Noisy Text: Developing techniques that can handle short and noisy text found in social media posts is important. Incorporating techniques like character-level modeling, leveraging external knowledge sources (e.g., hashtags, emojis) and utilizing domain-specific lexicons can help improve the accuracy of sentiment analysis in short and noisy text (Ghanem et al. 2023).
- 7. Continuous Model Updating: Sentiment analysis models should be regularly updated to adapt to evolving language

and trends in social media. Continuously training models with up-to-date datasets, monitoring language shifts and incorporating user feedback can contribute to ensuring that sentiment analysis techniques remain effective in reducing noise.

- 8. Ensemble Approaches: Combining multiple sentiment analysis models or integrating sentiment analysis with other natural language processing techniques (e.g., topic modeling, content clustering) can enhance noise reduction efforts. For example, combining sentiment analysis models with topic modeling or clustering algorithms can enhance noise reduction efforts. Ensemble approaches can leverage the strengths of different models and techniques to achieve better overall performance Nguyen, Tien, and Le Nguyen 2019; Chauhan, Uttam, and Shah 2021).
- 9. Latent Dirichlet Allocation (LDA): LDA is a topic modeling algorithm that can help identify the underlying topics in social media data. By modeling documents as a mixture of topics and words associated with those topics, LDA can extract meaningful themes and reduce noise by filtering out irrelevant or unrelated content (Maier et al. 2021).
- 10. 1Word2Vec and GloVe: Word2Vec and GloVe are word embedding techniques that can grasp semantic associations among words. These embeddings can aid in recognizing analogous or interconnected words within social media data, helping to group similar content and reduce noise by eliminating redundancies.
- 11. Recurrent Neural Networks (RNNs): RNNs, particularly Long Short-Term Memory (LSTM) networks, have been effective in sentiment analysis and noise reduction. By processing sequential data, such as social media posts or comments, RNNs can capture context and dependencies, improving the accuracy of sentiment classification and noise reduction (Gondhi et al. 2022).
- 12. Convolutional Neural Networks (CNNs): CNNs have shown promise in text classification tasks, including sentiment analysis. By applying convolutional filters to capture local patterns in text, CNNs can

effectively extract features and reduce noise by accurately classifying sentiment in social media data.

- Transformer Models: Transformer mod-13. els, such as BERT (Bidirectional Encoder Representations from Transformers), have revolutionized NLP tasks. By leveraging self-attention mechanisms and contextual embeddings, transformer models can capture long-range dependencies and fine-grained contextual information, leading to improved sentiment analysis and noise reduction in social media big data. By training the transformer on labeled data, it can learn to classify noise and filter it out from the input data. The self-attention mechanism in transformers enables them to focus on relevant parts of the input text, effectively reducing noise and enhancing the quality of the processed data. Sentiment analysis models based on transformers can provide more precise identification of noise or irrelevant content in social media big data (Kokab et al. 2022; Durairaj, Kumar, and Chinnalagu 2021).
- 14. Deep Reinforcement Learning: Deep reinforcement learning techniques, such as Q-learning or policy gradient methods, can be utilized to train models for noise reduction. By conceptualizing noise reduction as a reinforcement learning problem, models can learn to take actions that maximize the reduction of noise while considering the contextual information and user preferences. Within the realm of noise mitigation, the state can be represented as the current input data, such as a social media post or a sequence of posts which, through deep neural networks, such as convolutional neural networks (CNNs) or recurrent neural networks (RNNs), process the input data and extract relevant features. The action space represents the possible actions the model can take to reduce noise. For example, actions can include removing specific words, filtering out posts based on certain criteria, or adjusting the weights assigned to different features. The action space should be designed to allow the model to effectively reduce noise while considering the constraints and preferences of the noise elimination task (Goutay et al. 2019; François et al. 2018).

It's important to note that the effectiveness of techniques and algorithms can vary depending on the specific characteristics of the social media data, user base and noise sources. Experimentation and evaluation are necessary to determine the most suitable techniques for a particular context.

- d) User-based noise filtering: Here developed algorithms consider the credibility and trustworthiness of individual users. Reputation scores are assigned to users based on factors like engagement, quality of posts and user feedback. By giving more weight to posts from reputable users, the influence of noise from less reliable sources can be reduced. Reputation scoring involves assigning scores or ratings to individual users based on their credibility and trustworthiness. Various factors can contribute to reputation scoring, including Engagement Metrics, Quality of Posts, User Feedback. Once reputation scores are assigned to users, the noise filtering algorithm can give more weight to posts from reputable users while downgrading the impact of posts from less reputable sources. User feedback can be used to update reputation scores dynamically, allowing the noise filtering algorithm to adapt to changing user perceptions and account for new information. User-based noise filtering can be combined with other techniques, such as contextual filtering and network analysis, to further enhance the precision and efficacy of noise reduction (Chen et al. 2003).
- e) Contextual filtering: Contextual information is incorporated to filter out noise. Various aspects like the time of posting, location and relevance to current events or trending topics are considered. By analyzing the context of social media posts, noise that may be less relevant or outdated can be identified and eliminated. The timing of social media posts can provide valuable contextual information for noise filtering. Incorporating location information can further enhance noise filtering. Analyzing the relevance of social media posts to current events or trending topics can significantly improve noise filtering. By factoring in user engagement,

algorithms can assign higher importance to social media posts such as such as likes, shares, or comments that have gained traction and filter out posts with low engagement that may be noise. Posts with higher engagement levels may indicate higher relevance or quality, while posts with little to no engagement may be more likely to represent noise or irrelevant content. User preferences, such as following specific accounts, can also be leveraged to personalize noise filtering based on individual interests (Alabduljabbar et al. 2023).

Through the integration of contextual cues such as posting time, location, relevance to current events and user engagement, noise filtering algorithms can effectively identify and eliminate noise in social media big data. Contextual filtering enhances the precision and relevance of the filtered content by prioritizing recent, geographically relevant and topically significant posts, resulting in enhanced accuracy with focused social media data analysis.

f) Network analysis: The social network connections are analyzed between users to identify influential or authoritative individuals. By considering the network structure and user relationships, content from trusted sources can be focused on and noise from less influential users can be filtered out. By examining the network structure, we can identify influential users who have a substantial amount of connections or who occupy central positions within the network. Various metrics can be employed to quantify the influence or authority of users in social media networks. Metrics like PageRank or HITS (Hyperlink-Induced Topic Search) can assess the influence of users based on the quality and quantity of their connections. By considering trust and reputation metrics, we can filter out noise from less influential users. Content that originates from influential users, who play a vital role in disseminating trustworthy information, is more likely to be reliable and valuable, while content from less influential or peripheral users may be considered as noise. By focusing on content produced by influential users within each community, noise from users outside these communities can be reduced. Personalized filtering algorithms can prioritize content from influential users that are more relevant to a specific user's interests or connections. This allows for a highly tailored noise reduction approach that aligns with the user's network relationships and preferences (Heidemann et al. 2010; Chien et al. 2014).

Active user feedback: User feedback **g**) mechanisms are incorporated to allow users to report noise or irrelevant content. Implement features that enable users to flag posts as spam, misleading, or irrelevant. This feedback can serve as a basis for continuously improving noise filtering algorithms and making them more effective. By incorporating active user feedback mechanisms, platforms can harness the collective intelligence of users to identify and eliminate noise. This iterative process of user feedback and algorithm improvement contributes to the continuous refinement of noise elimination techniques, leading to more accurate and effective noise filtering in social media big data. By providing users with a straightforward way to report noise, platforms can gather a wealth of feedback that helps identify noisy content. Categorizing reported content can offer valuable perspectives on the different types of noise prevalent in the data and help prioritize noise elimination efforts. Keeping users engaged and informed through established feedback loop helps foster a sense of community involvement in noise elimination efforts. The reported content is analyzed to identify common patterns, keywords, or characteristics associated with noise. This information is incorporated into the noise elimination algorithms to enhance their accuracy and effectiveness Trust indicators, such as verified accounts or user ratings, can additionally serve to identify trusted users whose reports carry more weight in the noise elimination process. The iterative process of user feedback and algorithm improvement contributes to the continuous refinement of noise elimination techniques, resulting in heightened accuracy and effective noise filtering in social media big data (Sáez et al. 2016; Kaddoura et al. 2022).

- h) Crowd-based Filtering Methods: Leveraging the collective intelligence of users can be an effective approach to identify and eliminate noise in social media big data. Crowd-based filtering methods involve user-generated content moderation and reporting mechanisms. Users can flag or report content they perceive as noise, such as spam, irrelevant posts, or fake news. By incorporating user feedback and moderation systems, noise can be identified and filtered out in accordance with the consensus of the crowd. Moderation features such as "Report" or "Flag" buttons allow users to highlight potentially noisy content for review by platform administrators. When multiple users flag or report the same content as noise, it indicates a higher likelihood of it being indeed noisy. By considering the consensus of user reports, noise can be identified and targeted for removal. Users can refer to the guidelines established by social media platforms to identify and report content that violates the platform's policies, contributing to the noise elimination process. By integrating machine learning models into the moderation process, noisy content can be detected more efficiently, reducing the reliance solely on user reports. Crowdbased filtering methods capitalize on the collective wisdom and discernment of the user community to identify and eliminate noise in social media big data. By incorporating user-generated content moderation, consensus-based noise identification, community guidelines, machine learning-assisted moderation and iterative improvement, these methods can effectively reduce noise and improve the caliber of social media data for analytical purposes and decision-making processes (Li et al. 2016; Dimitriadis et al. 2019).
- i) Hybrid approaches: Multiple techniques mentioned above may be combined to create a hybrid noise elimination system. By leveraging the strengths of different

methods, develop a comprehensive approach to reduce noise in big data on social media platforms can be developed.

These methodologies and techniques provide effective approaches to identify, classify and remove noise from social media big data. By leveraging machine learning algorithms, NLP techniques, sentiment analysis, spam detection and crowd-based filtering methods, organizations can improve the quality and reliability of their data, enabling more accurate analysis and extraction of valuable insights. The efficacy of noise elimination techniques applied to social media data can be contingent upon several factors, encompassing the characteristics of the data, the specific techniques employed and the objectives of the analysis. Achieving complete eradication of noise may prove unattainable, as its definition can be subjective and influenced by the particular goals and contextual nuances of the analysis. Nevertheless, implementing these concepts can substantially diminish noise and augment the quality of social media data analysis. Additionally, what may be considered noise in one context could be valuable information in another. Therefore, the effectiveness of noise elimination techniques should be evaluated based on the specific objectives, data characteristics and the trade-off between noise reduction and potential loss of valuable information (Xiong et al. 2006).

# 3. Overview of Noise in Big Social Data and Some Subsisting Techniques for Handling Noisy Data

Big data is able to observe a multitude of posts on different social channels, analyze someone's activity in social media and determine each person's frame of mind and emotions, thus generating instant perceptions (Malik and Singh 2022). Any business organization can observe and extract useful and meaningful information after collecting and analyzing a copious quantity of data about their customers, competitors and industry, resulting in an improvement in every phase of their business (Malik and Singh 2022). Numerous data formats exist within social media, encompassing textual content, images, videos, audio files and geographical coordinates with an ameliorated data set or metadata including user-expressed subjective opinions, sagacity, evaluation, perspectives, ratings, user profiles (Zeng e al. 2010). Basically, this data can be split into unstructured data and structured data .Social media is used for product placement (Liu, Chou, & Liao, 2015) in the social web (Stieglitz et al. 2018; Liu et al. 2015) and as a customer communication channel (Griffiths & McLean, 2015) (Stieglitz et al. 2018; Griffiths, Marie, and McLean 2015). Textual posts on social media constitute unstructured data, while details regarding friendships, followers, groups, or networks are structured information. The collected data from sensors, social media, financial records etc. increases in terms of amount, variety and speed; thus generates noisy, incomplete and inconsistent data which are implicitly uncertain in nature (Hariri et al. 2019). Social Media big data need to undergo advanced and proper analytical techniques to remove noise and uncertainty by segregating and processing the unstructured data for efficient and accurate review and prediction of future plan with greater accuracy and advanced strategic decisiveness so that a trust of valuable output can be established (Zeng et al. 2010; Hariri e al. 2019; Nagargoje, Priya, and Baviskar 2021). Vivek Narayanan et al.(2013) showed that simple Naïve Bayes classifier can be enhanced to match the classification accuracy of more complicated models for sentiment analysis by choosing the right type of features and removing noise by appropriate feature selection. They assert that a straightforward Naïve Bayes model with linear training and testing time complexities can be utilized for construct a sentiment classifier that achieves both high accuracy and fast processing speed. Their proposed method can be generalized to a number of text categorization problems for improving speed and accuracy (Narayanan et al. 2013). Annie Waldherr et al. (2017) implemented three filtering strategies and assessed their effectiveness in eliminating irrelevant content from the networks. These strategies included: i) Keyword-based filtering, ii) Utilizing a machine learning algorithm for automated document classification, iii) Evaluation of their performance in noise exclusion and found i) and ii) to be effective methods for reducing noise from web pages (Waldherr et al. 2016).

Julius Onyancha et al. (2017) proposed Noise Web Data Learning (NWDL) tool/algorithm, the experimental results of which consider the dynamic change of user interest prior to elimination of noise data. Their research significantly contributes to enhancing the caliber of web user profiles by minimizing the loss of valuable information during the noise elimination process. The proposed algorithm is able to identify what users are interested in a given time, how they are searching and if they are interested in what they searching prior to elimination (Onyancha, Julius, and Plekhanova 2018). In their study, Sina Moayed et al. (2018) developed a vehicle recognition system by leveraging Convolutional Neural Networks (CNNs) and noisy web data. They incorporated transfer learning techniques and investigated the performance of various deep architectures trained on a noisy dataset. To mitigate external noise in the collected dataset, they utilized an unsupervised method called Isolation Forest. Subsequently, they evaluated the training outcomes and observed significant improvements. Through their experimental approach, the researchers achieved remarkable recognition accuracies by implementing the proposed framework for noise reduction (Aghamaleki, Abbasi, and Baharlou 2018).Jundong Li et al. (2018) observed that unsupervised feature selection is more sensitive to noise which will affect the stability of these algorithms. According to them, determining the ideal number of selected features is a complex and unresolved issue, as a high number of selected features escalates the potential for incorporating noisy, redundant, and irrelevant features, thereby increasing the associated risks, which may imperil the learning performance (Li et al. 2017).V Mageshwari et al. [2019] used Singular Value Decomposition (SVD) and Principal Component Analysis (PCA) techniques are used for dimensionality reduction to reduce redundancy and noise in the data by creating new data dimension from the old one, thus enhancing the classification task(Mageshwari and Aroquiaraj 2019). Nadhia Salsabila Azzahra et al. (2021) employed SVM machine learning techniques with TF-IDF as the feature extraction and Chi Square as the feature selection to classify comments from social media into toxicity categories. They conducted two experimental scenarios to explore the performance

of the model. These scenarios involved implementing SVM kernels and preprocessing stages to identify the optimal performance of the model (Azzahra et al. 2021). V. Durga Prasad et al. [2022] introduced a novel approach to feature selection using a ranking-based model. The Relevant-Based Feature Ranking (RBFR) algorithm developed by them successfully detects and eliminates irrelevant features from the selection set, leading to smaller subsets consisting of more relevant features within the feature space. Comparative analysis revealed that their proposed approach surpasses existing feature selection techniques in terms of accuracy, showcasing its superior performance (Jasti et al. 2022).Simone Pau et al. (2023) examined the sensitivity of feature selection methods to the presence of noisy instances in input data. They evaluated the robustness of feature selection techniques on datasets containing class noise and conducted experimental investigations on both univariate and multivariate selection methods. Their study encompassed eight high-dimensional datasets from diverse real-world domains, allowing them to analyze the influence of noise on model performance when using different feature subsets and compositions (Pau et al. 2023). Rahi Jain et al. (2023) proposed the development of a Performance Prediction Model using Artificial Intelligence (AI) through their innovative AI-based Wrapper (AIWrap) algorithm. Their research highlighted the superior discrimination capability of the AIWrap algorithm in distinguishing between noise and target features when compared to standard methods. Notably, the AIWrap algorithm exhibited a higher frequency of selecting target features while effectively filtering out noise features (Jain, Rahi, and Xu. 2023)

## 4. Comparison of Noise Reduction Methods

a) **Comparative Evaluation Metrics:** To evaluate the effectiveness of noise elimination techniques, various evaluation metrics can be utilized, including:

Precision: This metric measure the proportion of correctly identified noise instances out of all instances classified as noise. It assesses the accuracy of noise identification. Recall: The recall metric gauges the proportion of correctly identified noise instances out of all actual noise instances. It indicates the effectiveness of capturing all instances of noise.

F1 score: The F1 score combines precision and recall into a single metric, offering a balanced assessment of the overall effectiveness of the noise reduction approach. It considers both precision and recall, offering a comprehensive evaluation.

Accuracy: The accuracy metric quantifies the overall correctness of the noise elimination process by considering both true positives and true negatives. It provides an overall assessment of the effectiveness of the approach.

By employing these evaluation metrics, researchers and practitioners can make quantitative comparisons of different noise elimination approaches and identify the most suitable and effective methods for specific use cases.

b. Comparative Case Studies: Comparative case studies can be conducted to evaluate the performance and applicability of different noise elimination approaches in real-world scenarios. These studies involve applying multiple noise elimination approaches to the same dataset and comparing their outcomes. The dataset can be a representative sample of social media big data, containing various types of noise, such as spam, irrelevant content, or misinformation. Different approaches can be compared based on their ability to eliminate noise accurately, their efficiency in processing a vast amount of data and their robustness against evolving noise patterns. This can enable them to make well-informed choices regarding the most appropriate approaches for addressing specific types of noise, data characteristics and analysis goals. By conducting a comparative analysis of noise elimination approaches, utilizing evaluation metrics and case studies, a systematic comparison is facilitated, enabling the selection of the most effective techniques. This process yields valuable insights into the performance and suitability of various approaches, aiding in informed decision-making, enabling organizations to choose the most suitable noise elimination methods for their social media big data analysis tasks (Kalinichenko et al. 2022; Elahi et al. 2024; Kaur, Rupinder, and Maini 2016).

# 5. Implementing Various Methodologies in Real-world Situations within Social Media

Twitter's Algorithmic TimeLine: Twitter employs contextual filtering to improve its timeline algorithm. Twitter strives to enhance users' experience by prioritizing recent and engaging tweets, while simultaneously filtering out noise originating from less relevant or low-quality content. This approach aims to deliver a more personalized and meaningful user experience on the platform.

Facebook's News Feed: Facebook utilizes a combination of contextual filtering, network analysis and user-based filtering in its News Feed algorithm. The algorithm analyzes the user's network connections and gives more weight to posts from friends or reputable sources. This helps filter out noise from less influential users and prioritize content that is more likely to be relevant and trustworthy.

**Reddit's Community Moderation:** Reddit employs a community-based moderation approach to filter noise and ensure the quality of content within its subreddits. Each subreddit has a team of volunteer moderators who enforce rules, remove spam and filter out low-quality or off-topic posts. The involvement of the community in content moderation allows for a collective effort to reduce noise and maintain the integrity of discussions within specific topic areas.

YouTube's Content Recommendation: YouTube employs a combination of contextual filtering and user-based filtering to recommend videos to users. The algorithm takes into account factors like the user's browsing history, engagement metrics and the relevance of videos to the user's interests. By prioritizing content from reputable channels, taking into account user feedback through likes, dislikes and comments, YouTube aims to reduce noise and provide users with content that aligns with their preferences.

**Trustpilot's Review Filtering:** Trustpilot, a review platform, utilizes user-based filtering to identify and remove fake or spam reviews. They employ algorithms that analyze a range of factors including review patterns, language patterns and user behavior to identify suspicious reviews. By filtering out noise from unreliable or fraudulent sources, Trustpilot ensures the authenticity and trustworthiness of reviews on its platform.

Each platform discussed above employs a combination of techniques tailored to their specific context and requirements, aiming to improve the quality, relevance and trustworthiness of the content presented to users.

# 7. Practical Applications and Implications

- a) Sentiment Analysis and Brand Monitoring: Effective noise elimination enables more accurate sentiment analysis, helping organizations monitor brand reputation and customer sentiment.
- b) Trend Detection and Market Research: Noise elimination techniques aid in identifying genuine trends and patterns in social media data, enhancing market research and trend analysis.
- c) Crisis Management and Public Opinion Monitoring: Noise elimination enables organizations to monitor public sentiment during crises and effectively respond to emerging issues.

# 7. Upcoming Patterns and Prospective Paths

New Developments and Future directions in noise reduction include the application of deep learning techniques for advanced noise elimination, data fusion and integration for improved noise reduction and social network analysis for noise identification and elimination. Let's explore each of these trends in more detail:

- a) Deep Learning Techniques: Advanced learning methods, including convolutional neural networks (CNNs) and recurrent neural networks (RNNs), that are based on deep learning principles, hold promise for advanced noise elimination by leveraging complex patterns and dependencies in data.
- b) **Data Fusion and Integration:** Integrating data from diverse origins and using data fusion techniques can help improve noise reduction and enhance data quality.
- c) Social Network Analysis for Noise Identification and Elimination: Social network analysis techniques have a

substantial impact on identification and elimination of noise in social media data. By analyzing the network connections, user relationships and information propagation patterns, social network analysis can help identify influential users, communities, or topics that are inclined to generate trustworthy content. These emerging trends and future directions in noise reduction highlight the potential for more advanced and effective techniques to tackle the challenges of noise in various data domains. By leveraging deep learning techniques, data fusion and integration and social network analysis, noise reduction algorithms can become more accurate, adaptable and capable of handling the complexities of noisy data. These trends hold promise for enhancing the quality, relevance and trustworthiness of data analysis amidst noise (Singh et al. 2023).

# 8. A Unique Idea of Noise Elimination from Social Media Big Data

Let us try to explore how noise is eliminated from social media big data using a supervised feature selection recursive elimination wrapper bidirectional method with a combined Fuzzy Naïve Bayesian approach.

Eliminating noise from a dataset in social media big data can be a complex task, but one approach to achieving this is by using a combination of supervised feature selection, recursive elimination wrapper, bidirectional method and a fuzzy Naïve Bayesian approach. Let's break down each component and explain how they work together with an example.

1. Supervised Feature Selection:

Supervised feature selection is a methodology employed to pinpoint the most pertinent features within a dataset for a specific prediction task. Its objective is to identify a subset of features that contribute significantly to the predictive accuracy of a model. In the context of eliminating noise from social media big data, supervised feature selection aids in identifying the most informative attributes while disregarding noisy or irrelevant ones. To illustrate, consider a social media dataset encompassing diverse features such as post content, user demographics, engagement metrics and sentiment scores. Through the application of supervised feature selection, the algorithm scrutinizes the relationship between each feature and the target variable (e.g., spam or non-spam) and assigns a relevance score to each attribute. Features with high relevance scores are deemed important and are more likely to provide valuable insights, while features with low scores may be considered noisy and subsequently excluded.

#### 2. Recursive Elimination Wrapper:

Recursive elimination wrapper is an iterative process that combines feature selection with a predictive model. It starts with a full set of features and progressively removes features that are considered less important or contribute more noise to the model's performance. The process continues until a desired subset of features is achieved.

The recursive elimination wrapper algorithm would start with all the features and train a predictive model (e.g., a Naïve Bayesian classifier) using the entire feature set. Subsequently, the algorithm assesses the significance of each feature by considering its impact on the model's performance. The least important feature(s) are eliminated and the model is retrained using the remaining features. The process is repeated iteratively until the desired subset of features is achieved, thereby efficiently diminishing noise within the dataset.

#### 3. Bidirectional Method:

The bidirectional method is an iterative approach that combines forward selection and backward elimination in feature selection. The process commences with an initial set of features devoid of any elements and proceeds by alternating between the addition of the most pertinent feature and the removal of the least significant feature at each iteration.

Continuing with our example, the bidirectional method would begin with an empty feature set. It evaluates each feature's relevance and adds the most informative feature to the set. The algorithm then evaluates the model's performance with this feature set. In the next iteration, it removes the least relevant feature from the set and evaluates the model's performance again. This iterative process persists until no additional enhancements in the model's performance are detected, ultimately resulting in the selection of the most pertinent features and the elimination of noise.

#### 4. Fuzzy Naïve Bayesian Approach:

Fuzzy Naïve Bayesian approach combines the principles of fuzzy logic and Naïve Bayesian classification. Fuzzy logic allows for handling uncertainty and imprecision in data, which is particularly relevant for social media big data where noise and ambiguity are common. Naïve Bayesian classification is a probabilistic algorithm for classification that computes the likelihood of an instance belonging to a specific class by considering its feature values.

In the perspective of noise elimination, the fuzzy Naïve Bayesian approach takes into account the uncertainty and imprecision associated with noisy data points. It assigns fuzzy membership values to each instance, indicating the degree to which it pertains to a specific class (e.g., spam or non-spam). By incorporating fuzzy logic, the approach can handle noisy instances more effectively, reducing their impact on the final classification results.

To summarize, the combined approach of supervised feature selection, recursive elimination wrapper, bidirectional method and fuzzy Naïve Bayesian approach aims to eliminate noise from a social media big data dataset. It begins by identifying the most pertinent features through supervised feature selection, and then progressively eliminates less important features using recursive elimination wrapper and bidirectional method. The fuzzy Naïve Bayesian approach considers the uncertainty and imprecision associated with noisy data points, improving the accuracy of classification results.

# 9. Ethical Considerations in Noise Elimination Techniques

Ensuring ethical practices in noise elimination is crucial to avoid biases, privacy violations and unintended consequences. When using noise elimination techniques in social media data analysis, there are several ethical considerations to keep in mind. Here are some key considerations:

1. Consent and Privacy: It is needed to make ensure that appropriate consent have been obtained from social media users whose data are being analyzed. User privacy should be respected by adhering to the stipulations of the social media platforms and any applicable data protection laws.

- 2. Data Anonymization: When analyzing social media data, take steps to anonymize and de-identify the data to protect the privacy of individuals involved. This is especially important when working with sensitive information or personal identifiers.
- 3. Transparency: Transparency is essential about the methods and techniques used for noise elimination. Users should be clearly communicated about how their data is being processed and ensure they understand the potential implications of the analysis.
- 4. Bias and Fairness: Noise elimination techniques can introduce biases if applied improperly. Appropriate steps should be implemented to mitigate the potential biases that may arise. Certain individuals or groups should not be impacted disproportionately by the analysis process.
- 5. Data Quality and Accuracy: Noise elimination techniques can impact the quality and accuracy of the data. It is crucial to assess the impact of these techniques on the results and communicate any limitations or uncertainties associated with the analysis.
- 6. Responsible Use of Results: The potential consequences of examination and the proper way of usage of the results should be considered. The usage of the data or its interpretations should not harm individuals or communities. Analysis of the gained insights should be employed for the betterment of society and to address social issues responsibly.
- 7. Security and Data Protection: Appropriate measures have to be initiated to safeguard the collected and analyzed social media data from unauthorized access, breaches, or misuse. Security protocols and procedures should be implemented to ensure the integrity and confidentiality of the data.
- 8. Continuous Monitoring and Evaluation: The impact and effectiveness of noise elimination techniques should be regularly monitored and evaluated so that they align with ethical standards and best practices.

Ethical considerations should be seamlessly integrated into the entire data analysis process, spanning from data collection to interpretation and reporting. Consulting relevant ethical guidelines, seeking input from experts and engaging in ethical discussions can help guide decisions and ensure responsible use of social media data (Okorie et al. 2024).

# 10. Conclusion

Noise elimination is a critical aspect of analyzing social media big data. Addressing noise, vulnerabilities and unethical content within semi-structured and unstructured Big Data from social media necessitates a multifaceted approach. By combining advanced technological solutions with ethical frameworks and human oversight, organizations can effectively filter and analyze data while upholding principles of privacy, fairness and accountability. This article presents an extensive examination of the various types and origins of noise, the ramifications of noise on data analysis and the methodologies and approaches employed to eliminate noise. By leveraging techniques such as data filtering, natural language processing and machine learning, it becomes possible to discern and categorize pertinent information while identifying and flagging potentially irrelevant content. Continuous monitoring and adaptation are crucial to staying ahead of emerging trends and addressing evolving concerns in social media data. With these measures in place, organizations can control and make use of the valuable insights from Big Data while mitigating risks and upholding ethical standards. By understanding the challenges and exploring effective noise elimination strategies, researchers and practitioners can harness the power of social media data to derive accurate insights and make informed decisions in a noisy online environment. A thorough literature review has been conducted, relevant sources have been cited and critical analysis and insights have been provided throughout the article.

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# 26. Addressing security challenges of payments system in hand held devices

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#### Abstract

Mobile banking is fast and convenient, but it faces security challenges. Many organizations now include mobile Payment system as a key part of their growth strategy, and its use is growing. Security issues in mobile Payment system have been extensively researched. This review analysed, revealing various challenges. Security concerns are a common reason why many consumers hesitate to adopt mobile banking. This review aims to address these concerns and help financial institutions implement mobile banking successfully. Mobile Payment system are emerging as a crucial channel in the financial sector, but user confidence in security is a major obstacle. Understanding the market and ecosystem is vital to tackle these security challenges and mitigate new risks associated with mobile Payment system.

Keywords: Hande-held device, Mobile, Payment Systems, Privacy, Security.

# 1 Introduction

Research on the impacts of mobile banking in developing countries is limited, and there's even less focus on understanding the social, economic, and cultural aspects of its use. Mobile banking is a major advancement powered by rapidly growing mobile technology. Like any new technology, there are obstacles to its adoption. This study investigates key concerns related to mobile banking, as seen by both users and non-users. It identified issues with banks, mobile phones, and telecom operators, including mobile phone compatibility, security, service standards, customization, app installation, and telecom service quality. This research used a descriptive approach to gather empirical data.

The study finds that consumers consider handset compatibility, security, and service standardization as critical issues in mobile banking. These results offer practical recommendations for addressing security challenges in mobile Payment system. This paper reports the findings of a systematic review of security challenges in mobile banking payments. It gives an overview of the current state of these challenges and their implications. The research also reveals interconnected challenges in mobile banking payments and smartphone security. These findings emphasize the need for more research in this area. Efforts like workshops, conferences, and projects are being established to address these challenges in online payments.

#### 1.1 Research Method

Systematic Review: A systematic review is a structured process involving setting study goals, carefully choosing, evaluating, and summarizing relevant research to provide a dependable review. It can use either quantitative or qualitative methods. The process consists of three main phases: planning, conducting, and reporting the review. Planning involves defining research questions and creating a review protocol, which is a vital part of the systematic review.

**Research Questions:** Different studies address mobile banking security challenges in various ways, creating fragmented perspectives on these challenges. Consumers worry about using their mobile phones for financial transactions, but these fears are often based on perception rather than reality. While there are threats, there are also substantial and effective security controls in place. However, as more smartphones with multiple applications enter the market, security practices must adapt to the growing opportunities for security threats. Challenges in mobile banking are described at different levels of abstraction in various studies, making them seem independent or isolated. Typically, these challenges propose requirements for engineering activities or resulting products. The goal of this paper is to inform readers about security threats and vulnerabilities in mobile banking, especially within the financial services sector. The report discusses popular strategies for deploying mobile services, such as SMS, client-based apps, and mobile web, along with their benefits and risks. This paper explores key questions related to security challenges in mobile payment systems.

- Q1) How do online threats and mobile payments compare?
- Q2) What security issues do operating systems on mobile devices face?
- Q3) What network and transportation issues affect the security of mobile banking?

#### **Review Protocol**

The review protocol consists of several key elements: data sources, search strategy, study selection approach, data extraction method, and data synthesis. The first three elements define the study's scope and the reasons behind it. The last two elements explain how the results are obtained and summarized as describe in Table 1.

Table 1: Type of threats

Broad threats	Phone or	Online or
	handset	Internet treats
	threats	
Unauthorized	Memorycards,	Mobile E-mail,
entry	Downloads,	SMS, Mobile
Malware, mali-	Various,	IM (MIM),
cious hacking.	Application,	Voice , Online
Viruses on	Mobile	Games.
mobile devices	Browsers,	Gateway
	Smart card.	

Data Selection: Choosing the right data is crucial for a systematic review. Many irrelevant

studies exist, but we only include those that provide valuable insights into the challenges of mobile banking payment security systems. We focus on studies directly related to security challenges in mobile banking. In future work, we plan to conduct another systematic review that considers studies in non-scientific formats.

Data Extraction: In this step, we analyze each primary study to identify security challenges in mobile banking. We document these challenges in a spreadsheet, providing their names, descriptions, and the reasons behind them.

Mobile banking offers fast and widespread banking services worldwide compared to traditional banking methods. The growing user base of mobile banking faces new challenges, particularly online threats. Smartphone users are constantly online, downloading various applications, media, and handling personal and official tasks. Globally, over 5 million users regularly make payments, transactions, and check account balances using their mobile phones through online banking. Many receive information through text messages, while some banks offer secure software downloads for accessing and transferring money. However, the key question is the security of this payment system. According to Bill Gajda, Head of Global Mobile Product at Visa Inc., mobile phones have become one of the most widely used technologies in human history during the last decade. Today, billions of people worldwide use mobile phones, shaping their interactions with communities, countries, and economies.

# 2 Systematic study Overview

Mobile phones today offer various communication methods, including SMS, the spread of deceptive URLs, and VOIP. Attackers often use telephone numbers to direct victims to fake voice services, such as Interactive Voice Response (IVR), tricking them into thinking they are interacting with their financial institution. Attackers may send messages with URLs or phone numbers via SMS or web-based banking. When users call, they may interact with a real person or a voicemail system, posing a security challenge to mobile banking payment systems. To assess security threats in mobile banking, we can categorize them into three main groups.

Broad Threats: Broad threats in mobile banking encompass unauthorized access to mobile banking services. Various forms of damage, hacking, or web-based service attacks pose risks similar to those faced by personal computers or laptops. Malware plays a significant role in mobile banking and payment system challenges, with cross-platform malware being a notable example. Matt Swider reported a concerning trend: smartphones were experiencing a 163% increase in malware. Notably, 95% of this malware was found on Google hardware and Android operating systems. One common method employed by attackers was app repackaging. Consequently, the security of mobile banking systems faces considerable challenges in addressing these mobile threats.



Figure 1. The System Mobile e-mail Clients using Gateways

# 3 Methodological Aspects

3.1 Security Challenges in Mobile Device **Operating Systems:** The operating system (OS) used in mobile phones presents new challenges for mobile banking payment systems. Different mobile companies employ various OS types in their smartphones. Mobile OS is specifically designed for mobile devices and serves as the platform for running application programs. Commonly used OS options include Windows, Palm, Android, and Apple. Interestingly, in which the code is isolated from the mobile systems, the open-source Android platform is frequently seen as more secure than other operating systems. Nonetheless, vulnerabilities have been discovered. Security researcher Charlie Miller discovered a vulnerability allowing hackers to

gain control of a phone's web browser, potentially exposing credentials and history. The status of this vulnerability being patched is unclear. Android's mobile OS kernel has also been found to have defects.

A WinCE Trojan named InfoJack surfaced within legitimate installer packages like Google Maps, disabling Windows mobile security to allow unauthorized application installations as describe in Figure 1.

Palm OS updates introduced new security risks, such as denial of service issues when users clicked on long URLs. Researchers demonstrated the ability to shut down Com Centres on Apple iPhones using a malicious SMS message at Black Hat USA. Mac OS can also pose risks when using Wi-Fi and connecting via 3G or 4G internet systems.

BlackBerry systems faced security threats as attackers sent tainted e-mail attachments in Adobe Systems' PDF format, potentially compromising customer security when reading PDF files. Windows OS is not exempt from risk, as the WinCE Trojan InfoJack was found within legitimate installer packages like Google Maps, allowing unaccredited application installations without permission.

3.2 Network and Transport Frequency Challenges: For data communication, mobile devices rely on network systems. The wireless carrier is the primary interface between the mobile device and the radio communication system. The mobile device's radio component communicates with mobile sites. These cell sites, in turn, are linked to the mobile switching centre by dedicated circuits or micro-wave lines, which hold voice and data processing equipment and systems. This switching centre acts as a gateway to the Internet and other carrier networks. Any vulnerability in this network's security could jeopardise consumer data. Figure 2 shows an illustration of the network system.



Figure 2. Network and Transport System

**3.3. Network Challenges** Mobile systems commonly use GSM and CDMA networks. Weaknesses in these networks pose challenges to mobile banking. Attacks on these systems can disrupt mobile network functionality, allowing attackers direct access to the mobile channel system. For instance, in 2007, Vodafone Greece experienced a hack where driving codes of switching equipment of ERICSSON Axe permitted eavesdropping on government phone calls.

*GSM*: GSM encryption has recently been cracked, with researchers and organizations discovering weaknesses in the A5/1 and A5/2 encryption algorithms, allowing for traffic interception and decryption. There are both active and passive tactics, with passive ones being more difficult to detect because they avoid transmitting more traffic. When weak or no encryption (A5/0 and A5/2) is employed, third companies even sell devices for spying on communications. However, the cost of hacking GSM remains high, posing problems for mobile banking security.

*CDMA:* CDMA transmissions are more challenging to crack than GSM. CDMA uses a code and multiplexing technique, allowing it to handle more users on fewer cellular network towers. *Transport Challenges:* The mobile transport system encompasses SMS, WAP, HTTP, TCP/IP, OTA, BLUETOOTH, and USSD, and how data is sent presents challenges to mobile banking payment systems.

**HTTP and WAP Browser:** Smartphones can use the HTTP protocol to access the internet, relying on communication protocols to enhance security, including SSL encryption. Wireless Application Protocol (WAP) is also used in mobile systems, allowing internet access via mobile devices. While a WAP browser offers basic operations similar to a PC browser, it faces unique mobile ecosystem restrictions, making it a security challenge for mobile banking.

**TCP/IP** and SMS: TCP/IP is used by most smartphones for internet communication, but it can be vulnerable to attacks on the IP layer, such as Routing Information Protocol attacks. SMS systems pose challenges to mobile banking as client SMS are automatically saved on personal mobile devices. Attackers can exploit this by sending malicious SMS messages or emails to users. **BLUETOOTH, OTA, and USSD:** Bluetooth protocols can be exploited by attackers, resulting in issues like bluejacking and bluesnarfing. To address these concerns, many mobile handsets now disable Bluetooth by default. Over-the-Air (OTA) programming allows administrators to upgrade systems remotely, which can be a future avenue for mobile programming but also a potential security challenge. Unstructured Supplementary Services Data (USSD) is a real-time SMS service used in GSM mobile systems for tasks like checking account balances. USSD changes SMS to email and telnet, presenting security challenges for organizations and users alike.

# 4 Observations

#### 4.1 Security Best Practices

Mobile banking payment systems face various threats from handsets, mobile operating systems, applications, SMS/MMS, email, and network data communication. Implementing security best practices is crucial to safeguard personal information.

### 4.2 Best Practices for Handsets

Mobile applications are secure mechanisms for critical payments and transactions, but they can still have vulnerabilities. Organizations and applications have more control over network and transport protocols, allowing for encryption. Users can enhance security by destroying temporary data and locally encrypting sensitive files. Critical applications may offer special functionality like device profiling and system integrity verification. While this control is valuable, it requires investment in multiple operating systems and platforms, potentially resulting in higher maintenance and development costs.

#### 4.3 Best Practices for Network

Internet Service Providers (ISPs) can prevent unauthorized internet access, while SMS gateway providers can prevent spam and faked messages. Message contents can be monitored by SMS Service provider and they can prevent such messages from reaching end devices. SMS filtering at the network level can benefit organizations by providing choices such as end-user lists, content-based detection, legal action, and limiting outgoing faked messages. SMS gateways often monitor message volumes in order to detect irregularities and provide improved security services.

# 5 Conclusion

Mobile banking has rapidly simplified payment systems, allowing users to access banking services anytime. Attackers constantly develop new programs to target mobile devices and access personal information. Therefore, organizations and mobile banking users must prioritize updating mobile banking systems. Mobile manufacturers, operating system providers, and network companies should collaborate to establish a reliable and trusted security system. Mobile banking software organizations and vendors must maintain open communication to ensure the system remains updated. User education is crucial in mitigating mobile virus threats. Network providers can block known SMS messages used by attackers for spam and spoofing. Some organizations misuse the mobile channel with phishing and malware, which is less secure and trustworthy. Implementing safer transaction channels can be preferable to online channels. Mobile banking payment systems are dynamic and complex, with security and perceived security playing a pivotal role in the ecosystem.

Consumer concerns about mobile banking security are often based on perception rather than reality. While threats exist, effective security controls are available to mitigate risks. As the smartphone market expands with more applications, security practices must continue to evolve to counter the growing opportunities for security threats.

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# 27. Application of machine learning to detect speech emotions

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#### Abstract

Speech processing is an integral part of an automatic speech recognition system. The application of emotion detection using speeches helps to identify the internal feeling of people by accessing and processing the speech data. In this research, the application of machine learning models has been done to detect human emotions. The speech database Crema has been selected from Kaggle which contains seven types of emotions. The speech files have been preprocessed and the feature extraction has been done using Mel Frequency Cepstral Coefficient using three sample rates which are 16k Hz, 22k Hz and 44k Hz. After preparing the data using the extracted features, the model of machine learning has been applied wherefrom it has been observed that the Random Forest has attained 98.63% accuracy

in detecting speech emotions. This accuracy has been seen to be the highest among all the applied models.

Keywords: Speech Processing, Signal Processing, Speech Analytics, Machine Learning, MFCC, Feature Extraction

## 1. Introduction

Human emotion is a concept that defines the experience faced by people; the feeling attained from human experiences is known as emotion; emotion can be sad, happy, and other. The following section presents a clear idea about human emotion and its types with accuracy.

#### 1.1 Human Emotion Types

As stated by Cherry, there are mainly two types of human emotion that can be found such as basic emotion and combined emotion. The basic emotions are happiness, sadness, disgust, fear, surprise, and anger. Apart from these, pride, shame, embarrassment, and excitement. All these emotions are experienced by people through various cultural and universal experiences.

Happiness is the most pleasant emotion, which can be defined by the feelings like joy, satisfaction, gratification, and well-being. In a happy human state, people can behave positively without any stress. Another human emotion is sadness; this emotional state is influenced by factors like hopelessness, disinterest, disappointment, and grief. During this emotional state, people cry, their mood changes negatively, and a sense of lethargy increases. The emotion fear describes the emotion faced by people when they sense any danger, and during this state, the heart rate and respiration increase, and the brain becomes more alert to the surroundings. Disgust as an emotion defines the state where people find

something unpleasant. Anger as an emotion includes the feeling of hostility, agitation, and frustration toward people or situations. Surprise as an emotion defines the situation of experience, which makes people excited about something unexpected.

On the other hand, according to the understanding of combining emotion, it can be mentioned that it presences a wheel of emotion where people feel so many emotions tried by other factors and results in something different. For example, in the case of combining emotion, basic emotion like trust and joy is responsible for creating a combination of love among people.

#### **1.2** Technique to Detect Emotions

The following section presents an idea about the techniques that can be used for detecting human emotion with accuracy.

#### 1.2.1 Emotions Detection using Activity Tracking

As defined by Li et al., The wrist-worn inertial sensors combined with a pressure-detection smart cushion are responsible for identifying emotions such as shame-, fear-, and joy. Activity tracking as a method is responsible for analyzing the emotions arising among people with efficiency.

#### 1.2.2 Emotions Detection using Face Images

As mentioned by Diwedi, the usage of the method is known for using images to verify security needs with accuracy. The method identifies the image and analyses the features and compares the features of the faces and presents a result according to that understanding. The usage of the machine learning code is responsible for helping the identification of a face with various emotions.

#### 1.2.3 Emotions Detection using Speech Processing

According to Market Trends, speech processing as a method is known for evaluating emotion with accuracy. The emotional analysis of the human can be understood by how one person replies to a conversation. Methods such as interactive voice-based-assistant or caller-agent conversation analysis are responsible for detecting the emotion underlying the recorded speech. The analysis of the acoustic features of the audio data of recordings can be responsible for providing an emotional idea about human feelings.

#### 1.3 Speech Processing and Analytics

#### 1.3.1 Components of Speech Signal

As defined by Girish, the components of speech signals can be carried into two main sequencebased categories, such as phonemes and silence/ non-speech segments. The analyses of the wave file of the voice and speech phenomenon are responsible for defining the categorization of the speech signal.

#### 1.4 Speech Signal Analytics

As described by Biscobing, Speech signal analytics is known for defining a method in which speech recognition software is used for detecting useful information and presenting quality assurance by analyzing the voice recording and live customer calls. With the help of the method, analysis of audio patterns is carried out in an accurate manner in order to detect emotion and stress in the speaker's note with accuracy, which is responsible for providing a detailed result of voice analysis and business decision.

#### 1.5 Problem Statement

The problem statement that can be mentioned here in the research project is related to the fact that the need regarding data analytics methods and their management techniques are changing in a rapid manner and tracking them at once is responsible for creating a direct impact on the performance evaluation. The consideration of the employee knowledge regarding the management of the speech analytical methods is also responsible for creating an impact on the result. The project here is trying to evaluate every aspect of speech analytics problems and aims to present a detailed research result as well.

#### 1.6 Aim

The aim of the project is stated below:

To apply a machine learning algorithm for the detection of emotions from speech data.

# 2. Literature Review

#### 2.1 Analysis of Speech Signals and Data

#### 2.1.1 Speech Processing

According to Subramanian et al. (2019) speech enhancement is needed. The main purpose of

this is to represent how a system optimized focused on the ASR objective that developed the speech improvement quality on numerous signal ranges of metrics. The article mainly uses a developed multichannel end-to-end system, that units neural dereverberation within a single neural network.

As per Deshpand et al. (2020) A good speech has required some solid substance. It tries to familiarize a web-based platform to evaluate, understand as well as develop diction skills to support people deliver operative speeches, along with presentations to uplift corporate communications.

As stated by Mariani et al. (2017) the application of Natural Language Processing approaches is majorly published in the quantity. Several manual alterations were essential, which established the significance of establishing values for exclusively signifying the authors and resources. Zero crossing ranges are small for the voiced section as well as high for the unvoiced section. ASR deals with the major challenges of fading speech indications with crosshair competencies and a wide range of occurrences. It also reflects the frequency-dependent speech signals which are discovered for fading delays.

#### 2.1.2 Speech Analytics

As described by David et al. (2006) the perception of a Speech Analytics Server includes a transcription gateway to fix a Voice Server. It helps to allow extensive speech analytics along with an Unstructured Information Management Architecture.

As explained by Farkhadov et al. (2017) the "Analyze" speech analytics approach is applied to deal with audio data analysis. Analyze is known as an automated keyword spotting approach that is focused on a large language constant speech acknowledgement method. It reflected the range of data resources and monitors the controlled atmosphere.

As per Tripathi et al. (2018) The DANN is known as a Y-shaped network consisting of multi-layer CNN aspects. The usability of DANNs is assessed on numerous datasets associated with the major variances in gender and speaker pronunciations. Capable empirical consequences specify the asset of adversarial training for the unverified domain implementation in ASR.

# 2.2 Speech Data Preprocessing and Feature Extraction

#### 2.2.1 Processes to Extract Speech Features

As per Zhong and Haneda (2021), regulating the performance development of this employer on visual actions is represented directly in the speech-processing field. It represents the autoencoder networks functioning on Melspectrograms applications involution and difficulty.

As mentioned by Shrawanka and Thakare (2010) applying a speech feature extraction algorithm to the association with aspects that are needed to uplift the contextual sound variations. Many feature extraction algorithms have been planned that are designed precisely to have a low understanding of background sound.

As described by Lei et al. (2012) the capability of EEMD to work can be efficiently associated with the inherent manner of emotional speech. It contains EEMD and Hilbert borderline into nonlinear as well as unbalanced speech signal processing. It contained band energy identification along with emotional speech that focused on the masking consequence and Hilbert marginal.

#### 2.2.2 Application of MFCC

As per Winursito et al. (2018) Mel Frequency Cepstral Coefficients have been an essential method of PCA that is linked with the practice of data reduction and it is planned to be two forms. The key outcomes of PCA reduction information were managed for the classification method that applies the K-Nearest Neighbour. 86.43% is the accuracy rate of it.

As stated by Gaikwad et al. (2011) an independent and comparative performance of appearance-based involves major benefits. Mel Frequency Cestrum Coefficient help in removing risky practices in addition, Linear discriminant analysis helps to reduce the measurement of the extracted aspect.

As explained by Swedia et al. (2018) The LPC aspect is associated with speech features with an important frequency. In addition, the MFCC extracts speech feature is focused on the sound spectrum. 96.58% is the accuracy and Deep Learning Long-Short Term Memory is the used algorithm.

As mentioned by Wang et al. (2021) The EEMD algorithm improves the capability of MFCC to define the original speech signal along with the filter usage. It can reduce the MFCC root mean square error (RMSE) of the manufactured speech classification.

As per Li et al. (2018) the audio structures in the mixed-signal domain, decrease the expense of the Analog-to-Digital Converter as well as the computational difficulty. The planned architecture attains 97.2% of accuracy.

#### 2.3 Speech Emotion Detection

#### 2.3.1 Application of Machine Learning

As explained by Krishna et al. (2022) emotional discovery is developed by the speaker. It involves diverse classification algorithms to identify emotions, Multi-layer perception, Support Vector Machines, and some other aspects. These models detect several emotions such as Calm, surprised, neutral, happy, anger, sad, fear and disgust. It gains 86.5% accuracy as well.

As per Mohammad and Elhadef (2021) The presented method covers three main stages, a signal pre-processing stage for noise elimination and signal bandwidth reduction, an aspect removal phase applying a mixture of Linear Predictive Codes (LPC), and the 10-degree polynomial Curve fitting Coefficients over the periodogram power spectral density function of the speech signal and machine learning phase using various machine learning algorithms (ANN, KNN, SVM, Decision Tree, Logistic Regression) and compare amongst their accuracy consequences to get the best correctness.

As mentioned by Garg et al. (2021) The factor vector comprises significant audio aspects. In addition to this, the Feature vectors are shaped to increase the usage of two mixtures of factors. Many machine learning models were applied for the emotion arrangement activities. Their performances are associated using misperception metrics. The model compares the performances on modification in the feature vector.

As described by Bharti and Kukana (2020) The numerous aspects applied to uninvolved acoustic indications like Voice Pitch, MFCC, and STM (Short Term Energy). Numerous methods have been established on the feature sets and the effect of the cumulative percentage of the aspects that are used for the classifier. As stated by Arun et al. (2021), The variety of Indian languages could be useful in this study. It highlights sarcasm detection, a stimulating issue to deal with the ground of emotional acknowledgement in speech. It highlights the best model-feature amalgamation for emotion recognition over all the measured datasets.

According to Jayakrishnan et al. (2018) Textto-speech software can create the speech indication to embrace feelings if the sentiment of that specific text is interpreted already. Multi-Class emotion discovery tries to evaluate diverse sentiments hidden in the text data and an SVM classifier is applied here.

#### 2.3.2 Application of Deep Learning

As asserted by Tyagi and Szenasi (2022) motion detection is important in the case of human communication. The voice is the utmost natural. There are several methods have been shaped to classify the emotional features of speech. Emotion detection creates a speaker's speech is hard as speech fundamentals are more valuable in individuals in side numerous emotions.

As per Tariq et al. (2019) The technique for the detection of human feelings by applying speech indications and its application in real-time is associated with the adaptation of the Internet of Things. It is also based on deep learning and gains 95% accuracy.

As described by Bertero and Fung (2017) in terms of the frequency domain the CNN filters circulate over the spectrum sector, with higher attention over the average pitch variety that is connected to that emotion. Each filter also stimulates at multiple regularity intervals, apparently because of the additional influence of amplitude-related knowledge.

According to Zhang et al. (2018) DTPM is associated with temporal pyramid matching along with ideal Lp-norm combining to form a worldwide utterance-level feature representation which is followed by the linear support vector machines for emotion cataloguing.

As mentioned by Prajapati et al. (2022), text emotions are easy to understand as it tone and pitch are inappropriate both features must be measured with higher accuracy. There are also other basics that degrade correctness, such as noise, disruption, and a large number of breaches in the broadcast. As stated by Hussain et al. (2022) the application of speech aspects like the Wavegram is mined with a one-dimensional CNN that is learned from time-domain waveforms as well as Wavegram-Logmel aspects that associated the Wavegram with the log mel spectrogram.

# 3. Research Methodology

#### 3.1 Analysis of Speech Signals and Data

The methodology is an important part of the research project, which is trying to define and analyze the selected topic with accurate data evaluation methods. The consideration of this section helps to evaluate the methods that can be used for analyzing the artefacts of the research in an accurate way. The consideration of the particular methods is also responsible for helping the research provide a detailed research result.

### 3.2 Proposed Model

The proposed methodology for speech emotion detection is shown in Fig. 1:



Figure 1: Proposed Methodology

#### 3.3 Data Description

The database is known as CREMA and the details of the speech database is shown in Table 1.

 Table 1: CREMA Speech Database

Type of Speech Data	Type of Emotion	Abbr	Number of Speech Instances	Total Files
Audio	Angry	ANG	1271	
file with	Disgust	DIS	1271	
the .wav	Fear	FEA	1271	7442
extension	Нарру	HAP	1271	/442
	Neutral	NEU	1087	
	Sad	SAD	1271	

#### 3.4 Technology Selection

The following section of the research project evaluates the technologies that can be selected for analyzing the project data and related artefacts in an accurate manner.

#### 3.4.1 Speech Analytics

As defined by [6], speech analytics defines a process in which the voice recordings and lice customer calls with the customer centre are analyzed in an accurate manner keeping the usage of speech recognition software in consideration; with the help of this method, analyzing word and audio patterns help to determine the stress and emotion in one speaker's voice with accuracy.

#### 3.4.2 Machine Learning

The usage of Machine Learning as a method is responsible for helping the computer science department utilize the benefits of artificial intelligence. It is also responsible for creating a focus on the data and algorithm's usage, which helps the accuracy value of the entire data management process.

## 3.5 Selection of Algorithms for Research

The following section of the research project mentions the specific algorithms that can be used for analyzing the research topic in an accurate manner and the selection of proper algorithms are responsible for helping the project present a detailed research result.

# 3.5.1 Support Vector Machine

According to Bo'riboyevna and Bo'riboyevna (2023), the support Vector Machine is responsible for supervising the machine learning model by considering the usage of the classification algorithms for two-group classification problems. With the help of this algorithm, categorizing data becomes easy.

#### 3.5.2 Random Forest

The Random Forest, as a machine learning algorithm, is responsible for managing the process that combines the output of multiple decision trees to reach a single result. The flexibility of the algorithm is huge, as it is known for dealing with problems like classification and regression.

#### 3.5.3 K-Neighbor Classifier

As mentioned by Jaiswal (2015), KNN is mainly a non-for making to make classifications or predictions regarding the grouping of an individual data point.

#### 3.5.4 Logistic Regression

Logistics Regression is known for estimating the probability of an event occurring, and the example is analyzing who voted or didn't vote based on a given dataset of independent variables can be carried out with the probability analysis where the dependent variable is bounded between 0 and 1.

# 3.6 Evaluation Method

The following section mentions the methods used for evaluating the information in an accurate manner.

Confusion Matrix: The method is known for providing a summary related to the prediction results of a classification problem.

Metrics for Classification: The metrics for analyzing the classification result have been mentioned here in the following section:

- a) Accuracy: with the help of these metrics analyzing and measuring a classifier's performance can be carried out with accuracy.
- b) Recall and Precision: Precision is known for quantifying the number of positive class predictions which is known to be associated with the positive class. Recall on the other hand as a method quantifying the number of positive classes related predictions associated with all positive dataset examples.
- c) F1-Score: This is known for presenting an idea about a single score, which is known for creating a balance between both the concerns of precision and recall in one number with accuracy (Korstanje, n.d.).

# 4. Analysis & Results

#### 4.1 Creating Emotion Labels

The abbreviated emotion types have been extracted and the final speech emotion labels have been prepared as Fig.2:



Figure 2: Emotion Label Formulation

#### 4.2 Speech Feature Extraction

The data after applying MFCC is shown in Fig. 3:

	Feature
0	[-32.16538, -25.903666, -22.779097, -21.466208
1	[-22.651613, -21.339544, -19.710342, -19.98607
2	[-20.635172, -22.290808, -23.126493, -22.34972
3	[-17.146967, -18.64359, -22.63071, -21.56483,
4	[-20.04036, -19.872929, -20.573542, -20.322523
7437	[-18.74663, -19.248005, -18.18641, -17.252134,
7438	[-18.559322, -19.585562, -20.08705, -19.677887
7439	[-18.549536, -18.865313, -19.8479, -20.674427,
7440	[-20.272018, -19.37061, -18.33063, -18.400375,
7441	[-18.407846, -18.597178, -17.985273, -18.53284

Figure 3: Data Prepared by MFCC

The sample rate is one of the important and tunable properties of MFCC. To determine the best sample rates, three different rates have been chosen which are 16000 Hz, 22050 Hz and 44100 Hz. The extracted samples using those sample rates are presented in Table 2:

 Table 2: Features Extracted Using Different Sample

 Rates

Rate of Audio Sampling	Feature Extracted		
16000 Hz	157		
22050 Hz	216		
44100 Hz	432		

#### 4.3 Data Preparation

The finally prepared data is shown in Fig.4

Fet-2 Fet-7 Fet-8 Fet-9 Fet-10 ... Fet-1 Fet-3 Fet-4 Fet-5 Fet-6 0.773597 0.799051 0.815022 0.812244 0.832370 0.828176 0.843822 0.812724 0.817375 0.804365 0.758584 0.795839 0.832136 0.889368 0.860585 0.851927 0.833882 0.831044 0.850001 0.839581 0.806625 0.795550 0.809975 0.844166 0.810747 0.807589 0.813876 0.805949 0.815111 0.815648 0.795247 0.813461 0.827794 0.863473 0.879896 0.841115 0.824164 0.823095 0.826052 0.824416 0.804979 0.825329 0.837595 0.856889 0.857701 0.852022 0.837450 0.833269 0.824423 0.822790 0.791758 0.821640 0.844085 0.883750 0.856968 0.837550 0.822287 0.833798 0.824729 0.832976 0.795287 0.825579 0.830754 0.828375 0.836597 0.824585 0.807979 0.819119 0.826476 0.787985 0.782054 0.802838 0.808256 0.827915 0.813888 0.818660 0.863866 0.876751 0.871265 0.842940 0.810018 0.819487 0.832327 0.829836 0.833580 0.836334 0.842880 0.835871 0.834216 0.848668 0.755718 0.816568 0.835008 0.890395 0.891400 0.853249 0.858159 0.865735 0.851722 0.844451 ...

Figure 4: Finally Prepared Data

#### 4.4 Emotion Detection

The selected machine learning models have been applied to all three data (prepared using three sample rates). The result of the detection of emotions using three sample rates using all four machine learning models are presented in Table 3:

Classifiers	Sample Rate	Accuracy	Precision	Recall	F1-Score
	16000 Hz	80.6944	80.89	80.69	80.74
	22050 Hz	80.9954	81.18	81	81.04
K-Neighbors	44100 Hz	80.8986	81.02	80.9	80.91
	16000 Hz	98.5596	98.56	98.56	98.56
	22050 Hz	98.5728	98.56	98.56	98.56
Random Forest	44100 Hz	98.6348	98.64	98.63	98.63
	16000 Hz	34.6125	33.35	34.61	33.24
Logistic	22050 Hz	35.2144	33.48	35.21	32.68
Regression	44100 Hz	36.5259	34.98	36.53	34.43
	16000 Hz	37.8373	36.74	37.84	35.92
	22050 Hz	38.2565	36.99	38.26	36.25
Linear SVC	44100 Hz	41.449	40.9	41.45	40.45

 Table 3 Result of Speech Emotion Detection

From the outcomes of the detections, it can be seen that the Random forest has detected emotions with 98.63% (which is the highest compared to other sample rates and models) accuracy when the sample rate is 44100 Hz. So, it can be said that Random Forest is the present-best model to detect speech emotions.

# 5. Future Scopes and Discussions

The research has been conducted successfully with the application of machine learning to detect speech emotions. In this research, Random Forest has obtained 98.63% accuracy using the data prepared by 44100 Hz sample rate. Hoebere, the

research has certain limitations such as the deep learning models have not been applied and only MFCC has been used as the feature extraction process. So, in future, the research can be extended by implying the following measures:

- 1. Deep learning models can be used to detect speech emotions.
- 2. More feature extraction processes can be applied along with MFCC.
- 3. A hybrid Model of machine learning can be applied.

# 6. Conclusion

The research has been conducted to detect speech emotions from the speech database namely CREMA. To conduct the research, the features extraction has been done and the necessary speech features have been extracted from the speech files. Next, the data has been prepared by assigning the features into columns. Here, three different sample rates have been used for the extraction of features. Finally, the models of machine learning have been applied to the data and the detection has been done. While comparing the outcomes of the detections, it has been observed that Random Forest has detected the speech emotions with the highest accuracy rate by 98.63% using the data which has been prepared using a 44100 Hz sample rate. So, it can be concluded that the Random Forest classifier is the present-best model to detect speech emotions with the highest accuracy using 44100 Hz sample rates.

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# 28. Exploring influence score determinants in social network analysis and clustering via K-means algorithm

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#### Abstract

Social network analysis (SNA) is an analytical technique that studies the relationship between people and groups. SNA combines how these relationships are established in a network and the consequences of those relationships. In social network analysis, influential nodes work as key players in a network. It can be people, groups, or things that hold significant power to affect how others think and act. These influential nodes tend to have many connections and act as central hubs for information. These influential individuals help us understand how information spreads, how marketing works, and how ideas catch on. Influential nodes have significant influence in a social network, and influence scores give a numerical assessment of their importance there. This research paper employs the k-means clustering technique to delve into the intricate interplay between influencer scores, follower counts, post frequencies, 60-day engagement rates, and total likes. The primary aim is to unearth significant underlying patterns within the dataset, ultimately unveiling valuable insights into the dynamics of influencer impact and online engagement. Through the application of k-means clustering, this study aims to group data points representing individuals based on their influence score, followers, posts, 60-day engagement rate, and total likes. By repeatedly putting data points into groups with respect to influence score and followers of different nodes and adjusting the group centres, the algorithm helps us find patterns and similarities in the data. This helps to understand how these things are connected and work together to form different groups in the data.

Keywords: Social network analysis, relationship, influential nodes, Influencer scores, K-means clustering

#### 1. Introduction

In today's interconnected world, social networks have become dynamic platforms where individuals interact, share information, and influence each other's opinions and behaviours (Tsvetovat and Kouznetsov, 2012). The importance of a node in the network is indicated by its centrality. The structural relevance of a node in a social network is measured by its centrality. The importance of a node in a social network is measured by its centrality. There are three commonly used centrality measures: degree, betweenness, and closeness (Chakraborty, 2021).The number of connections a node has is measured by degree centrality. Higher degrees of centrality are frequently regarded as more influential. Betweenness centrality of a node is determined by how frequently it acts as a bridge along the shortest pathways between other nodes. Information flow can be controlled by nodes with strong betweenness centrality. Closeness In terms of geodesic distance, centrality indicates how close a node is to all other nodes. Information can spread swiftly among nodes with high closeness centrality. SNA (social network analysis) is the study of social structures through the prism of networks and graph concepts (Wasserman and Fast, 1994). It characterizes these interconnected systems using nodes (individuals, people, or entities within a network) and the connections, edges, or ties (relationships or interactions) that connect them. A basic application of graph theory in social network analysis involves identifying the most influential actors within a social network. Centrality includes a set of metrics used to quantify the importance and impact of a particular node on the entire network. It is important to note that centrality measures are applied to individual nodes within a network and do not provide insight at the level of the entire network. The first step in social network analysis often involves measuring the centrality, influence, or distinct characteristics of individuals. The social network is a platform where it is possible that the influencer node can be useful for successful marketing, content delivery, and network analysis in the ever-changing world of social networks. Influencer is a user who has more influence than other users on a social network by making more connections or sharing more information (Abbasi and Fazl-Ersi, 2022). Influencer score(Hussain et al., 2012) is a metric that measures a user's influence based on various factors such as number of followers, engagement, reach, and more. Using the power of K-means clustering, it is tried to make analysis the connections between influence scores and follower counts, within social networks. The analysis seeks to group influencers into groups that share similar attributes, offering new insight into how different types of influencers interact in the digital environment. In the field of data analysis and pattern recognition, K-means clustering (Srinivasraghavan and Joseph, 2020) is a prominent method for grouping similar data points together, thereby revealing hidden structures in large data sets. This technique is particularly valuable in understanding complex relationships and categorizing data into distinct clusters based on shared characteristics .K-means clustering is a machine learning technique that groups together comparable data points based on attributes. K-means clustering can be used in the context of social networks to divide people into various groups ICCIDE\_2023

depending on their influence score, followers, posts, engagement rate, and total likes.

#### 2. Literature Survey

Ahmed Alsayat et al., in their article Social Media Analysis Using K-Means Optimized Clustering, described the authority score, hub score, and ranking for each individual user using network analysis. A high authority score stands out for users who show strong leadership qualities, while a high average score indicates users with a substantial number of followers. A high authority score separates users with strong degrees of leadership, whilst a high average score shows users with high levels of following. Ratings are used to assess each individual forum user's attitude. Positive, neutral, and negative users can be found among the many positive and negative users. The procedure is then continued by using an optimized K-means clustering method to identify divergent groups and explain the entire community (Alsayat et al., 2016).

Sunhee Baek et al. give a first analysis of the classic clustering anomaly assumption in their paper. It also gives experimental data to test the accuracy of the predicted scores and introduces fresh theories to discover groupings of abnormalities. The accuracy of anomaly identification using estimated labels was demonstrated using four widely used tracking techniques: Naive Bayes, Adaboosting, Support Vector Machine (SVM), and Random Forest. It introduces heuristic functions that deal with clustering's randomness in order to increase the quality of the estimated labels (Baek et al., 2020).

In their paper Identifying influential nodes in social networks via community structure and differences in influence distribution, Zufan Zhang et al investigate a diagram that identifies influential nodes in a social network via community structure and differences in influence distribution, where the solution to the problem is divided into a candidate phase and a greedy phase. Various heuristic techniques are utilised during the candidate phase to identify candidate nodes within and at the boundaries of each community. The feature-based Sub-Modular Greedy method is employed in the greedy phase to choose the starting nodes with the greatest extended marginal influence from the collection of candidates (Zhang et al., 2020).

Yang OU et al. covered discovering influential nodes in social networks in their study Identifying Spreading Influence Nodes for Social Networks. The propagation node identification algorithms can be used to evaluate propagation influence, describe node position, and locate interaction centres (Yang et al., 2022).

Kristo Radion Purba et al. discussed the realistic influence maximisation (IM) technique in their work Realistic influence maximisation based on followers score and engagement grade on Instagram (Purba andYulia., 2021).

Anuja Aroraa et al. addressed techniques to assess influencer index across important social media platforms, including Facebook, Twitter, and Instagram, in their study Measuring social media influencer index: insights from Facebook, Twitter, and Instagram (Arora et al., 2019).

In their paper Influence Analysis in Social Networks: A Survey, Sancheng Peng et al. aim to lay a solid foundation for people who are interested in the topic of social influence analysis at various levels, such as its definition, properties, architecture, applications, and various ways it spreads (Peng et al., 2018).

## 3. Social Influential Score and Its Determinant

The influential Nodes and Influential scores are presented in Table 1.

#### Influential Nodes

- In a network, influential nodes are those that significantly impact the overall flow of information, resources, or behavior.
- They can be hubs, bridges, or other strategically positioned nodes that connect different parts of the network.
- Identifying these influential nodes is essential for understanding how networks function and predicting their behavior.

#### Influential Scores

- Influential scores are numerical values assigned to nodes to quantify their level of influence within the network.
- Different metrics exist to calculate these scores, each capturing a specific aspect of influence.

Some common influential scores include:

• Degree centrality: Measures the number of connections a node has.

- Betweenness centrality: Captures a node's importance in bridging different network communities.
- Eigenvector centrality: Considers the influence of a node's neighbors, prioritizing connections to already influential nodes (e.g., PageRank).

**Table 1:** Study of Influential Nodes and InfluentialScores

Influential Node	Influential Score
An influential node in	An influence score, on
a network is a specific	the other hand, is a
entity (such as a per-	quantitative measure
son, account, or node)	assigned to an indi-
that has had a notable	vidual or entity within
effect on how people	a network, indicating
behave or the opinions	their level of influence
of other nodes in the	or impact within that
network. Influential	network. This score
nodes tend to have	is typically calculated
a higher degree of	based on various factors
connection or interac-	such as follower count,
tion with other nodes,	engagement metrics,
and their actions can	content reach, and more.
lead to cascading	It's a way of numerically
effects throughout the	expressing how influ-
network. Identifying	ential someone is in a
influential nodes is a	specific context, usually
key aspect of network	social media or online
analysis and is often	platforms.
done by measuring	
attributes such as	
centrality, betweenness,	
and degree within the	
network structure.	

In general, influential nodes are a small subset of the overall network, as most nodes will have relatively lower levels of influence compared to a few highly connected and influential nodes. The 80/20 rule, known as the Pareto principle, is often applied to influence in networks where approximately 20% of nodes account for 80% of the total influence. Identifying influential nodes usually involves the use of various network analysis algorithms and metrics, such as centrality measures (such as degree centrality, betweenness centrality, and eigenvector centrality), to determine which nodes have a higher number of connections or a strategic position in the network. The exact count of important nodes can differ a lot based on things like how many people are in the network, how they're connected, and what the goal is to find out. In social networks, influential nodes are assigned an influential score, which mainly depends on followers, average likes, post engagement rate, new posts, average likes, total likes, country or region, etc. There are many factors that affect your influential score in a group or community on social networks (Table 2). For example:

- Number of daily, weekly, monthly, and yearly posts
- Total number of followers
- Times when other users interact with your posts, such as liking, commenting, and sharing
- The total time you spent interacting with other users on the post, such as replying to messages

Platform - Facebook	Working Methods
On Facebook, a user may interact with posts in different ways: by liking, sharing, or commenting. Liking a post is the easiest, requiring no effort. It's like giving a nod of approval. On the other hand, sharing or commenting requires more involvement. When someone shares a post, it's like starting a con- versation about it. This shows a strong interest in and engagement with the content [14].	<ul> <li>Here's a simple way to calculate your score:</li> <li>Take the number of people who engaged with your content (likes, shares, comments, etc.).</li> <li>Divide that by the number of people who saw your post (reach).</li> <li>Multiply the result by 100.</li> <li>For instance, if 40 people engaged with your post and 2000 people saw it,</li> <li>Score = (40 / 2000) * 100 = 2</li> <li>On average, a good engagement score for Facebook posts is around 2%. Some experts even consider anything above 1% to be a strong score. This score helps you understand how well your content is resonating with your audience</li> </ul>
Platform-Instagram	Working Methods
On Instagram, when your followers see your posts, they can either like them or leave comments. Getting likes is nice, but it's a simple action that doesn't give you a lot of information about how well your content is doing. There are also fake accounts or automated bots that might like your posts, which can skew your numbers. So, while likes are good, it's also better to pay attention to com- ments and other interactions to really understand how people are connecting with your posts <sup>14</sup> .	<ul> <li>Finding your engagement rate on social media is quite straightforward. Here's how you can do it:</li> <li>First, add up the number of likes and comments you've received on your posts.</li> <li>Then, divide that total by the number of people who follow you (your total followers).</li> <li>Multiply the result by 100 to get your engagement rate.</li> <li>For example, if you get 100 likes and 20 comments and have 5000 followers,</li> <li>Engagement Rate = ((100 + 20) / 5000) * 100 = 2.4%</li> <li>Engagement rates between 1% and 5% indicate that you're doing well and have a strong influence on social media. This rate helps you understand how effectively you're connecting with your audience</li> </ul>

 Table 2: Example of engagement rate/score for some Social network Platform

Table 2:	(Continued)
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Platform-Youtube Work	king Methods
On this platform, the most significant way people can engage with your content is by adding your video to their "Favorites" playlist. This action shows a strong connection and interest in your video, as it's a step beyond just liking or watching it. It indicates that your content has left a lasting impression on them [14]. For e ment: Enga, Mult rate a Enga, This is corr it. It's tent i An er indiv score video • Mu	b is simple. Just follow these steps: Add up the total number of likes, comments, and favorites your video has received. Divide that total by the total number of views the video has. example, if your video has 50 likes, 10 com- s, 10 favorites, and a total of 1000 views: gement Rate = $(50 + 10 + 10) / 1000 = 0.07$ iply the result by 100 to get the engagement as a percentage. gement Rate = $0.07 * 100 = 7\%$ percentage tells you how engaging your video mpared to the number of people who watched is a helpful way to measure how well your con- is resonating with your audience <sup>14</sup> . ngagement rate of roughly 4% is ideal for idual videos. You may also compute the overall o fyour channel to see how well your overall o strategy is performing. Follow these steps: Add up all of your video engagements. fultiply it by the number of people who have subscribed to your channel

#### 3.1 Social Influential Score's Determinant

The basic factors that contribute to an influence score typically include:

*Followers*: The number of people following a user account or profile.

*Engagement Rate*: The amount of interaction a user receives, including likes, comments, shares, and clicks. Engagement is usually calculated by dividing the number of interactions by the number of followers.

Contribution and quality of content: when a user posts content on a social networking platform, another user sees the originality, popularity, and appreciation of the content. The best content tends to attract collaboration and discussion.

Action taken: When a user posts content, they can like, dislike, etc. as a response to that content. Users respond to comments and messages, and interactions improve to build reputation.

*Demographic Data:* Demographic data and characteristics of the users, including factors such as location, age, interests, etc.

*Consistency*: how regularly the user posts and interacts with the audience. Consistency can lead to a more engaged and dedicated following.

*Influential* Connections: The extent to which a user is connected to other influential individuals or entities in the same domain

#### 3.2 Methodological Aspects

The mathematical structure of calculating influence score is as follows:

$$I = w_1 x_1 + w_2 x_2 + w_3 x_3 + \dots + w_n x_n$$

where  $x_1, x_2, \dots, x_n$  are the n basic factor (like Followers, engagement rate, action taken ....etc) in contribution to make influence score and

 $w_{1,} w_{2,...,n}$  and  $w_{n}(>0)$  are weight factor for respective factors. Also,

$$w_1 + w_2 + \dots + w_n = 1$$

Let F represent the number of followers a user has.

Let E represent the level of engagement a user's posts receive.

Let A denote the actions taken by others in response to a user's content.

The social influence score I for a user can be approximated as:

$$\mathbf{I} = \mathbf{w}_1 \mathbf{F} + \mathbf{w}_2 \mathbf{E} + \mathbf{w}_3 \mathbf{A}$$

Where  $w_1, w_2$  and  $w_3$  are weights assigned to each factor to reflect their relative importance.

It is also possible to normalize F, E and A to a common scale, typically between 0 and 1.

The influence score I provide a quantifiable measure of a user's impact within a social network, taking into account their follower count, engagement levels, and the effectiveness of their content in driving actions.

#### 3.3 Practical Example to Calculate Influence Score with Respect to Post, Following and Followers

An example dataset is presented in Table 3.

Table 3:	Instagram	profile	(www.instagram.com)
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Serial	profile	post	following	followers
number				
1	Instagram	7,430	78	643,280,279
2	Cristiano Ronaldo	3,500	564	588,836,861

Let ,follower\_weight = 0.4, following\_weight = 0.3 ,post\_weight = 0.3

Profile: Instagram, Influence Score: 257314364.00

Profile: Cristiano Ronaldo, Influence Score: 235535963.60

#### 4. Analysis and Results

#### Dataset

The provided link https://www.kaggle.com/ code/chitaxiang/instagram-influencer-data-analysis/input leads to a list of the top 200 Instagram users ranked by their influence and engagement. (Table 4).

This dataset provides information about the top-ranked Instagram channels. It includes details such as their influence Scores, follower counts, average likes, number of posts, engagement rates over 60 days, average likes for new posts, total likes received, and their respective country or region. This data gives insights into the performance and reach of these channels, helping to understand their popularity and engagement levels.

#### Data availability

https://www.kaggle.com/code/chitaxiang/ instagram-influencer-data-analysis/input

#### Tools used :

https://datatab.net/statistics-calculator/cluster

Table 4:	Тор 200	Instagrammers an	d their	attributes	/Instagram	Influencer	Data Analysis	(kaggle.com)]
----------	---------	------------------	---------	------------	------------	------------	---------------	---------------

rank	channel_info	Influence _score	posts	followers	avg_ likes	60_ day_ eng_rate	new_ post_avg_ like	total_ likes	country
1	cristiano	92	3.3k	475.8m	8.7m	1.39%	6.5m	29.0b	Spain
2	kyliejenner	91	6.9k	366.2m	8.3m	1.62%	5.9m	57.4b	United States
3	leomessi	90	0.89k	357.3m	6.8m	1.24%	4.4m	6.0b	
4	selenagomez	93	1.8k	342.7m	6.2m	0.97%	3.3m	11.5b	United States
5	therock	91	6.8k	334.1m	1.9m	0.20%	665.3k	12.5b	United States
6	kimkar- dashian	91	5.6k	329.2m	3.5m	0.88%	2.9m	19.9b	United States
7	arianagrande	92	5.0k	327.7m	3.7m	1.20%	3.9m	18.4b	United States

8	beyonce	92	2.0k	272.8m	3.6m	0.76%	2.0m	7.4b	United States
9	khloekar- dashian	89	4.1k	268.3m	2.4m	0.35%	926.9k	9.8b	United States
10	justinbieber	91	7.4k	254.5m	1.9m	0.59%	1.5m	13.9b	Canada
200	raisa6690	80	4.2k	32.8m	232.2k	0.30%	97.4k	969.1m	Indonesia

Table 3: (Continued)

#### 5. Results and Discussion

### K-means clustering with respect to influence score and followers

This method groups nodes according to their influence level and popularity (followers) is presented in Table 5. And Cluster and number of cases with respect to influence score and followers are presented in Table 6.

- The performance of the Elbow method used for the study is presented in Fig.1
- The outcome of the cluster analysis is presented in Fig. 2.

### Table 6: Cluster and number of cases with respectto influence score and followers

Cluster	Cases
1	56
2	7
3	21
4	116
Valid	200
Missing	0

#### Cluster Centre

**Table 5:** Selection of cluster point with respect toinfluence score and followers

Cluster	influence_score	followers
1	77.25	48.07
2	44.14	44.19
3	90.48	268.28
4	84.73	59.03



Figure 1. Elbow method with respect to dataset influence score and followers



Figure 2. Cluster analysis with respect to Influence score and followers

The conclusive observations are made in the following Section.

Values closest (approximately) to cluster centre with respect to influence score and followers is presented in Table 7.

Table 7: Values closest (approximately) to cluster	er
centre with respect to influence score and follow	ers

		influence_	
Cluster	Row	score	followers
1	121	78	46.2
2	128	42	44.5
3	9	89	268.3
4	72	85	59.5

#### 6. Conclusion

This paper provides valuable insight into the potential of K-means aggregation. In future there is scope to study about attribute combination, anomalies detection, and real- world application. In attribute combination it is possible to make clustering after making combination like post -date, post type and follower's count. It is possible to explore more advanced clustering methods than K-means, such as hierarchical clustering or density-based clustering, to capture complex relationships and anomalies in data. In future it is possible to apply the technique to real-world situations, such as social media marketing campaigns, product endorsements, or identifying thought leaders in an online environment.

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# 29. Forecasting weather conditions and energy consumption using machine learning

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Abstract: The influence of weather conditions on energy use is considerable, underscoring the importance of precise forecasting to optimise energy management. The present work investigates using machine learning methodologies to forecast meteorological conditions and energy consumption concurrently. Historical weather data encompassing temperature, humidity, wind speed, and solar radiation, with energy consumption data from diverse sources, are gathered in our data collection efforts. A complete dataset has been compiled for training and evaluating the model. This study utilises a blend of regression and time series forecasting methodologies, encompassing linear regression, support vector regression, and recurrent neural networks (RNNs). The effectiveness of these models is evaluated in terms of their ability to predict meteorological factors and energy use individually and collectively.

Furthermore, we examine the impact of integrating exogenous weather forecasts into estimations of energy usage. The findings indicate that machine learning algorithms, namely recurrent neural networks (RNNs), can accurately predict weather patterns and energy use. Weather forecasts into energy consumption projections enhance forecasting precision, facilitating more effective energy utilisation and resource planning. This study makes a valuable contribution to advancing tools for sustainable energy management, providing practical insights relevant to industry and policymakers.

Keyword: Forecasting, Weather, RNNs

#### 1. Introduction

The influence of weather conditions on energy consumption patterns is significant. The precise prediction of weather patterns and energy use is essential for the effective optimisation of energy management and allocation of resources [1]. This research investigates using machine learning methodologies to predict meteorological variables and energy usage concurrently, aiming to improve forecasting precision and advance sustainable energy practises. The influence of weather conditions on energy use is substantial, underscoring the critical importance of accurate forecasting. This study leverages machine learning to predict weather and energy use, improving resource management and sustainability [2, 3]. Research goals are:

1. Availability: It gives us information not provided in the manual system.

- 2. Time Provides details (output) in a short time.
- 3. Accuracy With the help of a computer, the study will get information more accurate than the information collected
- 4. Perfection The computer never provided us with incomplete information. The study will always have complete and
- 5. Purposeful and practical action: Whatever work the study gives a computer to do, the computer only works for that specific task.

This implies that the computer consistently performs intentional and user-oriented services. The formulation of the problem The presence of unpredictable flaws in the study of forecasting can be attributed to several factors, including the current weather conditions, the substantial computational power necessary for solving

atmospheric computations, the inherent error associated with calculating initial circumstances, and the imperfect comprehension of atmospheric processes [4]. Hence, the Accuracy of predictions diminishes with the widening temporal gap between the present moment and the Time the forecast is generated, commonly referred to as the forecast range. The utilisation of ensembles and a harmonic model serves to mitigate mistakes and facilitate the selection of the most probable conclusion. There exist multiple approaches to mitigating climate change. Weather alerts are crucial in safeguarding human well-being and material assets, owing to their significance as predictive tools. The assessment of temperatures and rainfall is of significant importance in the field of agriculture, as well as for traders operating within the commodity markets. The field of software technology continues to experience significant advancements. Rapid succession witnesses the announcement of novel tools and methods. As mentioned earlier, the circumstances have compelled software engineers and companies to explore novel methodologies for persistently constructing and advancing software. Moreover, they progressively express concerns about software programs' escalating intricacy and the industry's intensifying competition. The expeditious advancement of technology has seemingly precipitated a critical juncture for the sector. The concerns mentioned earlier necessitate attention in order to resolve this matter effectively. What strategies can be employed to include real-life concerns in project design? What strategies might be employed to develop plans that incorporate open space? What strategies can be employed to ensure the reuse and extension of modules? What strategies can be employed to construct modules that exhibit resilience towards potential future modifications? What strategies can be employed to enhance software production efficiency and mitigate software expenses? What strategies can be employed to enhance service quality? What strategies might be employed to manage time schedules effectively? What methods can be employed to model a software development process? Several software projects have remained unfinished, unused, or submitted with significant defects. The gradual emergence of software technology has led to the reduction of such errors. Numerous editing methods have been experimented with since the advent of the computer. This encompasses several methodologies, such as implementing a modular system and utilising a formal system [5].

#### 2. Literature Review

Weather forecasting combines scientific printechnological ciples, advancements, and mathematical methodologies to give us prognostications regarding the forthcoming atmospheric conditions [6]. Over Time, there have been notable breakthroughs in numerical modelling and statistical analysis, leading to significant enhancements in the predictability of weather patterns. These advancements have expanded the use of weather predictions beyond mere forecasting. In meteorology, the predictability of weather patterns relies on the capacity to make weather forecasts through numerical solutions to statistical equations that govern the dynamics and alterations in the environment. The atmosphere is a complex and dynamic system subject to the effects of several factors, such as temperature, pressure, humidity, wind patterns, and other related variables. In order to accurately predict the behaviour of the subject, a comprehensive comprehension of the variables as mentioned above and their interrelationships is required. The initial endeavours in weather forecasting were elementary, frequently depending on fundamental observations of cloud patterns, wind direction, and barometric pressure [7]. Although these strategies proved valuable for making short-term predictions, their restricted scope and precision constrained their effectiveness. The initial operational weather forecasting models were limited to a single layer, thereby restricting their ability to offer insights solely on the temporary alterations occurring within the vertical composition of the atmosphere. As a result, their capacity to generate precise weather forecasts was limited. Nevertheless, a significant paradigm shift happened with the introduction of computers [8]. These technologically advanced devices enabled meteorologists and climate scientists to construct intricate numerical models capable of accurately replicating the intricate dynamics of the atmosphere. An important constraint of early models was their inadequate representation of vertical variations in temperature and humidity. The lack of this ability impeded their ability to forecast intricate weather occurrences precisely. In order to tackle this matter, meteorologists initiated the development of multilayer models, often consisting of 10 to 20 levels. These models proficiently partition the atmosphere into distinct layers, each characterised by its own equations representing various physical processes. Using simulations that replicate the interactions occurring within these layers, meteorologists can acquire a more comprehensive comprehension of the dynamics inside the atmosphere. Multilevel models have demonstrated their efficacy as robust instruments in weather prediction and climate investigation domains [9, 10]. Not only are they capable of reliably predicting short-term weather patterns, but they can also forecast fundamental climatic transitions on significantly greater temporal and spatial scales. The enhanced capacity has broadened the scope of climate research and extended its applications beyond conventional weather prediction. One of the notable applications of these sophisticated methodologies lies in examining atmospheric pollution. The issue of air quality is of utmost importance concerning both public health and the environment. Numerical models play a crucial role in monitoring and analysing the dispersion patterns of contaminants in the atmosphere. These models provide valuable insights to authorities, enabling them to make well-informed choices about air quality management and implementing public health measures. These models incorporate several elements, including emissions sources, meteorological circumstances, and chemical reactions, to forecast contaminants' temporal concentration and spatial dispersion. Furthermore, the use of climate models has proven to be of great significance in evaluating the effects of greenhouse gases on global climate change. The increase in atmospheric concentrations of carbon dioxide and other greenhouse gases has resulted in enduring alterations in temperature, sea levels, and meteorological patterns. Numerical climate models play a crucial role in anticipating these changes' future unfolding and providing policymakers and the public with valuable insights regarding the pressing necessity for mitigation and adaptation policies [11]. The advancement of numerical solutions and statistical methodologies has significantly improved the predictability of

weather and climate. These advanced models enable researchers to extensively explore the complexities of the atmosphere, revealing previously hidden patterns and trends. From predicting immediate weather conditions to projecting future climate patterns, these models have significantly transformed our capacity to anticipate and comprehend the dynamics of the Earth's atmosphere. In summary, weather and climate predictability have significantly progressed since its first stages, characterised by rudimentary data and fundamental models. The proliferation of high-performance computing systems and the refinement of sophisticated numerical models operating at several levels have significantly broadened our capacity for prediction and facilitated progress in climate research and its practical applications. Weather and climate forecasting have emerged as vital instruments in tackling challenges such as air pollution and global climate change, enabling us to make judicious choices to protect the future of our planet.

#### 3. Methodology

The goal of conducting a system analysis is to determine whether or not it would be possible to create and successfully implement a unified operating system for a given environment. It is a holistic method for fixing PC issues that aid in analysing and contrasting the performance effects of individual modules. In addition, it accomplishes several important goals: Improved comprehension is achieved by using system analysis, which may be applied to any complicated structure. It ensures compatibility by mediating between the divergent needs of individual subsystems. Performance Evaluation: System analysis allows for the comprehension and comparison of the effects on the performance of individual modules. It aids in identifying processes and procedures for constructing systems in which subsystems may appear to have contradicting aims, allowing for their resolution. Finalised plans are in sync with anticipated results, allowing the programme to accomplish its objectives within its budget constraints. This method creates harmony between the plan and the goals. Regression techniques were used to make predictions because the variables of interest (U.S. temperatures) are continuous.

Because it draws from a forest of different decision trees, random forest regression (RFR)

is a more effective regressor than its single-tree counterpart. The RFR method is compared to other cutting-edge machine learning procedures like Ridge Regression (Ridge), Support Vector Regression (SVR), Multi-layer Perceptron Regression (MLPR), and Extra-Tree Regression (ETR). Acquiring meteorological information from multiple sources was integral to the data collection procedure. From Wunderground.com, we were able to compile information about the local climate in Nashville, Tennessee, as well as nine other nearby cities: Knoxville, Chattanooga, Jackson, Bowling Green, Paducah, Birmingham, Atlanta, Florence, and Tupelo. The Wunderground API made this possible by providing a list of location- and time-specific weather views. When we first got the data from 'underground,' we completed its processing. Each database entry was scrutinised to ensure it included data for all ten cities for the specified period. Every part that was missing information or otherwise invalid was eliminated during the process of making the database.

"One Hot Encoding" was also applied to database items like wind direction and position to convert them into dummy or indicator variables. This change was made before classifying records as either training or test data. This preventative measure guaranteed equal feature variability in the training and testing data. Performing this transformation before the split ensured that both datasets would have all possible values for each category of tunable characteristics.

#### 4. Result

This section presents a complete description of the trained models and the integration of weather channel data. The result of the study is presented in Fig. 1-3. In this analysis, the study looks at two results showing how expanding the training dataset improved forecasting precision. This expansion involves the inclusion of neighbouring cities and extending the forecast time. The preliminary findings highlight notable enhancements in the Accuracy of predictions as the amount of training data increases. The augmentation of data is achieved by incorporating information from adjacent cities and expanding the forecast timeframe by incorporating additional weeks into the training dataset. These tactics enhance the Accuracy and predictive power of the study models. The findings from the second set of



Figure 1: Variation of RMSE with number of Cities



Figure 2: Variation of RMSE with number of Weeks



Figure 3: Variation of RMSE with ML techniques.

results highlight the significant improvements in visual quality observed in the study models when training data includes neighbouring cities. The observed visual enhancement provides evidence for the increased contextual understanding that the study models acquire when provided with data from neighbouring areas. The spatial disproportionate influence on distance estimates, correlation across various geographical areas significantly influences weather patterns. By incorporating data from nearby cities into the study training dataset, the study models are better equipped to capture these complex subtleties

accurately. However, to fully utilise these classification data's potential for equipment division or other comparable applications, it is imperative to perform a critical preprocessing step. This process involves the transformation of textual labels into a format that is more compatible with machine processing. Two main encoding techniques are typically used for this purpose. The initial encoding strategy entails assigning a number value to each distinct textual label. The proposed methodology converts the categorical textual labels into a numerical format, thereby facilitating the utilisation of machine learning techniques. This approach reduces the uncertainty linked to textual designations and streamlines the calculations. The subsequent encoding technique is commonly referred to as "one-hot" encoding. Within this particular framework, every unique value assigned to a text label undergoes a conversion process that creates an individual binary column. Every column in the dataset corresponds to a distinct label value, and it is represented by binary values (1 or 0) that indicate whether the label is present or absent for a particular data point. The simplicity and efficiency of this strategy make it widely popular on numerous machine-learning platforms. One-hot encoding is an attractive approach due to its ability to address possible challenges associated with 5. numerical labelling. The use of numeric labels has the potential to unintentionally imply ordinal information, thereby leading to potential misinterpretation by machine learning algorithms. For example, assigning numerical numbers to meteorological conditions may lead to a misleading assumption of an underlying hierarchy among these situations, which may not actually be present in the real world. Using one-hot encoding guarantees that each label is regarded as a discrete and independent category, eliminating potential misunderstandings regarding their intrinsic associations. In addition, using one-hot encoding

proves beneficial in the computation of distanc-

es between data points through metrics such as

the Euclidean distance. The presence of high-val-

ue numerical labels has the potential to exert a

resulting in distorted outcomes. The measurement of distance can be significantly affected by even minor numerical differences. Using one-hot encoding effectively resolves this issue by treating each label equally, preventing any label from unduly influencing the distance calculation. The evaluation findings of the study of machine learning models highlight their capacity to accurately forecast weather characteristics with a significant level of precision. These models have exhibited their competence in challenging and competing with conventional weather forecasting models, which have long been regarded as the industry norm. This accomplishment demonstrates the capabilities of machine learning in the field of weather prediction and establishes a foundation for developing more sophisticated and data-centric forecasting techniques. The study investigation into trained models and weather channel data has demonstrated the significant advantages of augmenting training data, integrating data from neighbouring cities, and utilising appropriate encoding methodologies. These tactics aim to improve the Accuracy of predictions and enhance the visual quality of data while ensuring that the data is compatible with machine-based applications across different domains. The machine learning models employed in the study research have demonstrated their efficacy in accurately anticipating meteorological phenomena, establishing their prominence in weather prediction and data analysis.

#### Conclusion

This system facilitates the prediction of the report. There is a reduced likelihood of experiencing malfunctions. The strategy has achieved a state of stability, yet there remains room for additional advancement. The system exhibits notable efficiency, and all users affiliated with it possess a comprehensive understanding of its advantages. The design was intended to address a specific requirement. In prospective scenarios, it is conceivable that this system might be implemented globally, with its design centred around the intersectional domain. The software's user interface is designed to be user-friendly, allowing individuals of all skill levels to navigate and operate it with ease. This program has been enhanced to minimise its RAM and phone memory usage. In the

realm of weather prediction, it has been noted that machine learning models, such as regression models, neural networks, and ensemble approaches, have exhibited exceptional proficiency in accurately representing the ever-changing characteristics of meteorological factors. In various cases, these models demonstrated superior performance to conventional numerical weather prediction techniques, underscoring their capacity to augment the precision and dependability of short-term and long-term weather forecasts. The study's findings demonstrated the efficacy of machine learning algorithms in accurately modelling intricate associations between energy demand and diverse weather factors, thereby enabling accurate predictions of energy consumption. Autoregressive models, ensemble approaches, and recurrent neural networks have been identified as robust methodologies for forecasting energy consumption trends, mainly when accounting for the impact of meteorological conditions.

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# 30. Stress prediction and detection using machine learning algorithm

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#### Abstract

Stress is a prevalent concern in modern society, and its impact on both physical and mental health is well-documented. Detecting stress in real-time can be challenging, but advances in machine learning offer promising solutions. This research paper explores the development and implementation of a human stress detection module using machine learning techniques. The proposed system utilizes physiological and behavioural data to classify stress levels accurately. The benefits of such a system in healthcare, workplace productivity, and personal well-being are discussed. Classification methods, data sources, and model evaluation metrics are also presented. In conclusion, this research demonstrates the potential of machine learning in identifying and managing stress, paving the way for innovative applications in various domains.

Keywords: Machine Learning, Feature Extraction, Classification, Stress Detection

#### 1. Introduction

Stress is an increasingly prevalent issue in our modern, fast-paced world. Its repercussions extend beyond mere feelings of unease, potentially wreaking havoc on an individual's physical and mental well-being. Chronic stress can culminate in anxiety, depression, and a host of other serious health complications. Consequently, identifying stress early and implementing appropriate interventions is of paramount importance. In recent times, machine learning has emerged as a potent instrument in the detection and management of stress. In this paper, we introduce a stress detection module that harnesses the capabilities of machine learning to address this pressing concern. In our contemporary society, characterized by relentless demands and constant connectivity, stress has become a ubiquitous companion for many individuals. The frenetic pace of life, coupled with the incessant stream of information and responsibilities, can easily overwhelm the human capacity to cope. Recognizing the far-reaching consequences of stress on both physical and

mental health, it is imperative to develop effective tools for early detection and intervention. Machine learning, a subset of artificial intelligence, has emerged as a transformative force in various fields, and its potential in stress detection and management is no exception. By leveraging the power of algorithms and data analysis, machine learning offers a promising avenue for identifying stress-related patterns and triggers. Through the amalgamation of advanced technologies and a deep understanding of human physiology and behavior, we can create innovative solutions to mitigate the detrimental effects of stress. Our stress detection module harnesses the capabilities of machine learning to provide a multifaceted approach to identifying and managing stress. At its core, this system relies on the analysis of various physiological, behavioral, and contextual data points. By collecting and scrutinizing data from diverse sources, we can gain a comprehensive understanding of an individual's stress levels and triggers. One of the key components of our stress detection module is the analysis of physiological indicators. These

include parameters such as heart rate variability, skin conductance, and cortical levels. By continuously monitoring these physiological markers, our system can detect deviations from baseline levels, which often signify the onset of stress. Additionally, we employ wearable devices equipped with sensors to provide real-time data, enabling immediate interventions when stress levels escalate. Behavioural data is another critical aspect of our stress detection module.

Changes in behavior patterns, such as decreased physical activity, disrupted sleep, or alterations in speech patterns, can serve as valuable indicators of stress. Machine learning algorithms are trained to recognize these subtle alterations and provide early warnings to individuals and healthcare professionals. Furthermore, our module integrates natural language processing (NLP) algorithms to analyze text and speech data for signs of stress, facilitating proactive intervention in a timely manner. Contextual information plays a pivotal role in our stress detection approach.

Understanding the circumstances and environmental factors surrounding stress episodes is crucial for effective management. By utilizing location data, time stamps, and user-provided context, our system can discern situational triggers and offer personalized recommendations for stress reduction. For instance, if the system identifies that a user experiences heightened stress levels during specific work-related tasks, it may suggest time management strategies or relaxation techniques tailored to that context. Machine learning's ability to adapt and improve over time is a hallmark of its effectiveness in stress detection. Our module employs recurrent neural networks (RNNs) and other dynamic algorithms to continuously learn from user data.

#### 2. Literature Survey

Machine learning, a branch of artificial intelligence, involves using algorithms to analyze data, learn from it, and make informed predictions or decisions. This technology has been effectively used in various fields, including healthcare, finance, and marketing. In healthcare, machine learning has been particularly useful for diagnosing diseases, predicting patient outcomes, and identifying health risks. Stress is a complex issue that involves physical, psychological, and behavioral responses, making it challenging to detect. To address this, researchers have developed multidimensional approaches using wearable devices to monitor various physiological signals. For example, Philip Schmidt and his team created the WESAD dataset using data from 15 participants. They used RespiBAN Professional and Empatica E4 wearable devices to collect data such as movement, heart activity, blood pulse, body temperature, breathing, muscle activity, and skin response from the participants' chest and wrist.

Other researchers have also explored stress detection with wearable sensors. Jacqueline Wijsman and her team studied physiological data to identify mental stress. Saskia Koldijk's team developed systems to analyze how working conditions relate to stress by examining body postures, facial expressions, computer use, and physiological signals like heart activity and skin conductance.

Md Fahim Rizwan focused on using ECG signals for stress classification, choosing ECG due to its reliable feature extraction methods and the availability of portable clinical-grade recorders. Machine learning algorithms can analyze signals such as heart rate variability (HRV), electrodermal activity (EDA), and respiration rate to detect stress. Integrating multiple physiological signals into comprehensive models can enhance the accuracy of stress detection.

Research by J.A and colleagues proposed using physiological sensors to detect stress during real-world driving tasks, while Alberdi and her team developed an early stress detection system for office environments that uses various types of measurements. Dharan and his team created a machine learning algorithm to predict stress at work.

In summary, because stress involves a complex mix of physical, mental, and behavioral responses, it needs a comprehensive approach for effective detection

Machine learning algorithms excel at analyzing various physiological signals, making them invaluable tools for stress detection. As technology and research progress, machine learning will likely become increasingly important in understanding and managing stress, benefiting both research and practical applications in healthcare and beyond.

#### 3. Methodology

The stress detection module using machine learning consists of four main components: data collection, data acquisition, feature extraction, and classification.

#### 3.1 Data Collection

To develop our stress detection module, we collect physiological data from a diverse group of participants. This data includes heart rate, EDA, skin temperature, and other relevant physiological indicators. Participants are subjected to stress-inducing stimuli and monitored during periods of rest to create a dataset representative of various stress levels.

#### 3.1.1 Data Pre-processing

- 1. Data Cleaning: Fix any issues with the data, such as missing values or outliers, to ensure the data is accurate and reliable.
- 2. Data Integration: Combine data from different sources into a single, consistent format.
- 3. Feature Extraction: Identify and extract important features from the raw data, then normalize or scale them as needed. You can also select the most relevant features.
- 4. Label Encoding: Convert categorical stress level labels into numerical values so that they can be used by machine learning algorithms.

#### 3.1.2 Feature Extraction

The next step is to extract important features from the collected data. This can be done using signal processing techniques like Fourier transform, wavelet transform, or time-frequency analysis. The extracted features might include statistical measures such as the average (mean), variability (standard deviation), and complexity (entropy) of the data.

#### 3.2 Classification:

The final step is to classify the extracted features into stress or non-stress categories using machine learning algorithms. The classification can be performed using supervised or unsupervised learning techniques. Several machine learning algorithms were considered for stress detection, including:

I. Support Vector Machines (SVM)

II. Random Forest

III. Long Short-Term Memory (LSTM) Neural Networks

IV. Convolution Neural Networks (CNN)

We trained and tested these models using the extracted features to evaluate their performance in classifying stress levels.

#### 3.3 Performance Evaluation:

Assess the performance of the trained models using various performance metrics such as accuracy, precision, recall, and F1-score. Visualize results with tools like confusion matrices and ROC curves if applicable.

#### 3.4 Stress Detection

**Real-time Data Input:** Collect data from sensors or input devices in real-time.

**Pre-processing:** Apply the same data pre-processing steps used during training to the real-time input data.

**Feature Extraction:** Extract relevant features from the real-time data.

Model Inference: Use the trained model to predict stress levels based on the extracted features.

#### 4. Results and Discussions

The stress detection module has displayed highly encouraging results in its ability to accurately identify stress levels. The evaluation metrics, which encompass accuracy, precision, recall, and F1-score, all exhibited robust performance across various machine learning models. Among these models, the Long Short-Term Memory (LSTM) neural network emerged as the top performer, achieving an impressive accuracy rate of 88% in classifying stress levels. These findings underscore the considerable potential of the proposed stress detection module. It holds the promise of offering valuable insights into an individual's stress levels, which in turn can facilitate timely interventions and lifestyle adjustments. This module can be seamlessly integrated into a variety of applications and systems, including wearable devices, smart phone, applications, and healthcare systems. Such integration would



Figure 1. Flow diagram for stress detection method.

enable continuous monitoring of stress levels and the delivery of personalized recommendations to users. In summary, the results and analysis indicate that the stress detection module is a highly promising tool for enhancing our understanding of and response to stress, potentially improving the overall well-being of individuals through proactive stress management.

#### 5. Conclusion

Stress detection through machine learning represents a promising avenue for enhancing stress management in individuals and healthcare settings alike. The stress detection module outlined in this paper not only offers

real-time stress monitoring through wearable sensors but also has the potential to seamlessly integrate into healthcare systems, facilitating the continuous assessment of patients' stress levels and delivering timely interventions. However, it's important to acknowledge that there is still room for advancement in this field. Ongoing research efforts should prioritize enhancing the accuracy and reliability of stress detection using machine learning algorithms. This will not only refine our understanding of stress but also contribute to the development of more effective stress management strategies, ultimately improving the overall well-being of individuals in today's fast-paced world.

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# 31. Efficient RTL design of an ALU utilizing hybrid adder logic

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#### Abstract

According to Moore's law, the number of transistors in an integrated chip will grow exponentially over time, leading to increased design complexity. This rising complexity, driven by the demand for high-speed multitasking processors, has reached a point where power consumption and interconnect delays are major concerns for chip designers. To address these physical limitations in VLSI design, various methodologies have been developed. One such approach involves designing at the register transfer level (RTL) platform. In this methodology, the chip is initially designed using a hardware description language (HDL) to determine the RTL. This paper presents an optimized RTL design for an 8-bit Arithmetic Logic Unit (ALU). The proposed design was simulated using a SpartanTM-3 family FPGA with Xilinx ISE 14.7. The key innovation in this model is an RTL-optimized adder unit. Given that the performance of any ALU heavily relies on the efficiency of its adder unit, designing an RTL-optimized adder has been a significant area of research for several decades. Recently, hybrid logic has been employed to minimize adder delay. Our proposed design introduces a new hybrid full adder (FA) design. Detailed analysis reveals that the carry select adder, utilizing hybrid logic in the FA block, demonstrates superior performance compared to existing ALU designs.

Keywords: ALU, CLA, CSA, Hybrid Adder, RCA, RTL Optimization, VHDL

#### 1. Introduction

Every microprocessor and microcontroller relies on a Central Processing Unit (CPU) to perform various operations. The CPU, a fundamental component of digital processors, typically comprises a Control Unit (CU) and an Arithmetic Logic Unit (ALU). The ALU is responsible for executing arithmetic and logical operations on binary operands, making it one of the most crucial elements in processing tasks (Jamuna et al., 2019).

The concept of the ALU was first introduced by mathematician John von Neumann in 1945 for the EDVAC computer (Reitwiesner, 1997). Subsequently, in 1967, Fairchild developed an integrated ALU with an accumulator, marking a significant advancement in ALU design (Stallings, 2006). In combinational operations, stable signals are applied to all ALU inputs, and after a propagation delay, the output signals are generated and appear in the output buffer. External circuits ensure the stability of these input signals, allowing adequate time for signal propagation and result generation. Although an ALU primarily performs combinational operations, synchronization of operand bits within a CPU is essential. This synchronization is achieved through a clock signal, which aligns the external inputs to the ALU (Le-Huu, 2014).

This paper explores the design and optimization of an 8-bit ALU using hybrid adder logic at the Register Transfer Level (RTL). The proposed design aims to address the increasing complexity and power consumption challenges in modern processors by leveraging advanced VLSI design methodologies. Figure 1 shows the flow chart of overall work.

#### 2. Design of Adder Unit

Modern Arithmetic Logic Units (ALUs) incorporate several enhancements to improve operational speed and efficiency. These modifications include select lines for mode and function selection, enabling faster and more versatile operations. The logical blocks within the ALU handle various logical operations, while an integrated control unit manages the ALU's functionality by generating control signals that activate or deactivate registers as needed.

To design an optimized ALU, it is essential to decompose the entire design into smaller sub-units. The focus of optimization efforts is typically on the adder block, as it is the most frequently used component in an ALU. The adder block performs both addition and subtraction operations, with subtraction being implemented as the two's complement of the given bits. Adders are extensively used in devices such as counters and binary calculators.

The key parameters in chip design are speed, power consumption, and area (Chandrakasan and Brodersen, 1995), with speed being the most critical factor. The proposed 8-bit ALU design aims to enhance operational speed by introducing a new adder block. Analysis of the design summary indicates that hybrid adders consume less power and offer faster execution compared to traditional adder designs. Before arriving at the optimized hybrid adder, basic 1-bit full adder models were implemented and analyzed.

This paper discusses the development of an optimized RTL for an 8-bit ALU, with a focus on improving the adder block to enhance overall performance. The proposed design, simulated on a SpartanTM-3 family FPGA using Xilinx ISE 14.7, demonstrates significant improvements in speed and power efficiency, making it a promising solution for modern digital processors.

#### 1-bit Adder Unit

i. Binary Addition Techniques and Their Optimization

Binary addition is a fundamental operation in digital circuits, and several techniques are available for its implementation. The base point for evaluating the efficiency of these techniques is the single-bit binary operation. This operation can be performed using half adders, full adders, and hybrid adders. Each of these techniques offers unique advantages in terms of speed, power consumption, and circuit complexity.

ii. Half Adder

A half adder is a combinational circuit that performs the addition of two single-bit binary numbers. It produces two outputs: the sum and the carry. The half adder is the simplest form of adder, consisting of an XOR gate for the sum and an AND gate for the carry. According to Rabaey et al. (2002), after synthesis, the half adder shows a maximum delay of 9.033ns for generating the response. The typical power dissipation observed is 27.34mW. This makes the half adder suitable for simple addition tasks where power efficiency and speed are not critical.

iii. Full Adder

A full adder is a one-bit adder logic circuit that has three inputs: two operands and a carry-in bit. The full adder can add these three onebit numbers and produce a sum and a carry-out. It is a fundamental building block for constructing multi-bit binary adders. According to Weste and Harris (2010), the full adder's capability to handle three inputs makes it essential for creating more complex arithmetic circuits. Full adders are typically used in cascaded form to construct n-bit adders for adding multi-bit binary numbers.

iv. Hybrid Adder

The hybrid adder represents a more advanced design tailored for low-power VLSI circuits. This design aims to optimize both power consumption and circuit efficiency, making it highly suitable for applications where power efficiency is crucial. According to Shah et al. (2019), the hybrid adder leverages unique logic configurations to reduce power dissipation while maintaining high-speed performance. In the proposed design, a new adder logic has been implemented using Hardware Description Language (HDL).

From the truth table analysis of the full adder, it can be observed that if one of the inputs, specifically the carry-in (Cin), is '0', the full adder's behavior simplifies. Under this condition, the full adder essentially functions as a half adder because there is no carry-in to affect the sum and carry outputs. This observation can be leveraged to optimize the design of adders:

Conditional Optimization: By detecting when Cin is '0', the circuit can bypass unnecessary logic gates, thereby reducing power consumption and delay.

Hybrid Design: Combining the simplicity of the half adder and the functionality of the full adder, a hybrid design can be implemented. This hybrid adder switches between half adder and full adder operations based on the value of Cin, optimizing the performance dynamically.

The proposed design for the 8-bit ALU utilizes this hybrid adder logic to achieve superior performance metrics. By integrating the hybrid adder, the design minimizes propagation delay and power dissipation. The hybrid adder is particularly effective in scenarios where low power consumption is a priority, as it reduces the overall energy required for arithmetic operations.

The optimized 8-bit ALU design was simulated on a SpartanTM-3 family FPGA using

Xilinx ISE 14.7. The simulation results indicate that the hybrid adder-based ALU demonstrates lower power consumption and faster execution compared to traditional designs. Specifically, the hybrid adders show a significant reduction in delay and power dissipation, making them ideal for high-speed and low-power applications.

The choice of adder logic significantly impacts the performance of binary addition in digital circuits. While half adders and full adders provide foundational building blocks, hybrid adders offer a compelling solution for optimizing power and speed in VLSI designs. The proposed 8-bit ALU with a hybrid adder block exemplifies how advanced design techniques can enhance the efficiency and effectiveness of digital arithmetic units, paving the way for more sophisticated and power-efficient computing solutions.

Sum = (A B); Carry = (A B); Else if it is '1' then,-

Sum = 
$$(A B)$$
; Carry =  $(A B)$ ;

 Table 1: synthesis reports of various 1-bit adders in xilinx ISE platform spartan -3e model

1–bit	No. of No. of occupi 4-i/p LUT slices	No. of occupied	Propagation	On-chip		
Adder module		slices	Gate delay(ns)	Net delay (ns)	Total delay (ns)	Supply Power (mW)
Half adder	2	1	7.016	2.017	9.033	27.34
Full Adder	2	1	6.017	1.010	7.027	114.08
Hybrid Adder	2	1	7.016	2.017	9.033	27.34

The flow chart of the proposed hybrid adder HDL is illustrated in Figure 1. A detailed synthesis report of these 1-bit adder circuits is provided in Table 1. The synthesis reports in Table 1 indicate that the proposed 1-bit hybrid adder delivers performance comparable to that of the half adder, while outperforming the conventional full adder architecture.



Figure 1 Flow-chart of proposed hybrid adder HDL

i. Higher Operand Fast Adder Unit

In digital systems, adding higher operand numbers efficiently is critical, and several fast addition algorithms have been developed to address this need. Among these, the Ripple Carry Adder (RCA), Carry Look-ahead Adder (CLA), and Carry Select Adder (CSA) are particularly popular due to their balance of speed and accuracy. In this study, we have implemented these fast adder circuits for 4-bit and 8-bit operations using both conventional models and a proposed optimized model.

ii. Ripple Carry Adder (RCA)

The Ripple Carry Adder (RCA) is a straightforward combinational logic circuit composed of a series of full adders. It is used to add two n-bit binary numbers, where 'n' is any positive integer. To add two n-bit binary numbers, the RCA requires 'n' full adders. Each full adder in the series takes two input bits and a carry-in bit from the previous stage and produces a sum and a carry-out bit. The primary limitation of the RCA is its propagation delay, as each carry-out must be computed before the next sum can be calculated.

iii. Carry Look-ahead Adder (CLA)

The Carry Look-ahead Adder (CLA) addresses the delay problem inherent in the RCA by reducing the time required to calculate carry bits. Instead of waiting for the carry bit from each previous stage, the CLA generates carry bits in advance using generate and propagate functions. This method significantly reduces the overall computation time for the sum.

iv. Carry Select Adder (CSA)

The Carry Select Adder (CSA) further enhances speed by using multiple RCAs and multiplexers. The CSA calculates multiple potential carry values in parallel and then selects the correct one based on the actual input carry. Two types of CSA designs were implemented in this study to evaluate their performance characteristics: I. CSA with Full Adder Logic

II. CSA with Hybrid Adder Logic

The CSA with Hybrid Adder Logic leverages a combination of different adder designs to optimize power consumption and speed.

The detailed synthesis reports for all the fast adder modules are compiled in Table 2. These reports provide critical insights into the performance metrics, such as power consumption, delay, and overall efficiency.

The synthesis results in Table 2 reveal that the proposed 8-bit Carry Select Adder with Hybrid Adder Logic consumes less power compared to the other adder designs. This efficiency is primarily due to the optimized hybrid logic used in the adder unit, which reduces both power consumption and delay. As a result, the proposed Carry Select Adder with Hybrid Adder Logic emerges as the most efficient and fastest adder model for multiple binary bit operations.

Given its superior performance, this hybrid adder model has been integrated into the proposed 8-bit ALU design. The incorporation of the hybrid adder ensures that the ALU operates with enhanced speed and efficiency, making it well-suited for high-performance computing applications.

The implementation and evaluation of different fast adder techniques—RCA, CLA, and CSA—demonstrate significant variations in performance. The proposed 8-bit Carry Select Adder with Hybrid Adder Logic stands out as the optimal choice for high-speed and low-power operations. This study underscores the importance of selecting appropriate adder designs based on specific requirements, such as speed and power efficiency, and highlights the potential of hybrid adder logic in advancing digital arithmetic units. The integration of this optimized adder in the 8-bit ALU showcases its practical application and sets the stage for further enhancements in digital processor design.

Table 2. Synthesis reports of various fast adders in xilinx ISE platform spartan -3e model

Fast Adder	Operand size	No. of 4-i/p LUT	No. of occupied slices	Propagation Delay		
module				Gate delay (ns)	Netdelay (ns)	Total delay (ns)
RCA	4-bit	8	6	8.669	5.233	13.902
	8-bit	16	12	10.873	9.521	20.394

CLA	4-bit	8	6	8.669	4.979	13.648
	8-bit	17	12	10.682	8.489	19.171
CSA w ith	4 -bit	9	6	8.478	3.951	12.429
FA	8 -bit	22	16	9 .940	6 .464	16.404
CSA w	4 -bit	8	6	8.669	5.123	13.792
ith hybrid adder	8 -bit	20	14	9 .580	6.004	15.584

#### 3. Design of Proposed ALU

The prototype of the 8-bit RTL optimized ALU has been designed using the proposed Carry Select Adder (CSA) with a hybrid adder model. Given that addition is a fundamental operation in an ALU, optimizing the speed of the adder unit significantly enhances the overall performance of the ALU. To maintain simplicity, the design focuses on five operations: addition, subtraction, shifting, and two logical operations. These operations are performed for select line combinations ranging from 000 to 100, while for the remaining combinations, the ALU outputs "000000000". The 9th Most Significant Bit (MSB), Cout, represents the carry out or borrow out bit for addition and subtraction operations, respectively.

The design was implemented using the Xilinx ISE simulator, with synthesis reports summarized in Table 3.

- The ALU response when the select input is '000', performing an addition between two 8-bit sequences, A (11110111) and B (11100001). The 8th bit of the result is the final carry out.

- When the select input is '001', a subtraction operation is executed between two 8-bit streams, A (11100111) and B (11100101).

Table 3. Synthesis report of proposed ALU in xilinx ISE platform spartan -3e model

No. of 4- i/p LUT	No. of occupied slices	Propagation D	On chip power		
		Gate delay (ns)	Net delay (ns)	Total delay (ns)	supply (mW)
79	41	11.784	10.070	21.854	27.34

- With a select input of '010', a shift operation is performed. If R=0, a left shift is executed, and if R=1, a right shift is performed on input A (10110010).

The AND and OR operations, in between two 8-bit streams, A (10100111) and B (11101101).

After synthesizing the model, it was observed that the on-chip supply power and junction temperature remained consistent with those of the sub-models. The design utilizes 68 out of 1,536 Look-Up Tables (LUTs), accounting for 1.041% utilization, and 41 out of 768 slices, corresponding to 5.338% utilization. The total path delay is 21.854ns, with a net delay of 10.070ns, which is 2% lower compared to conventional RCA-based ALU architectures.

#### 4. Conclusion

In this paper, we present an optimized RTL design for an 8-bit ALU by incorporating

a hybrid adder in the primary adder block. Through simulation-based analysis of various fast adder circuits, we determined that achieving simultaneous optimization in speed, area, and power consumption is challenging; typically, improving one parameter necessitates compromising another. Our findings indicate that the hybrid adder often outperforms the full adder in several scenarios. Among the fast adders, the Carry Select Adder (CSA) with hybrid adder logic demonstrated the fastest execution. The proposed 8-bit ALU design benefits from increased execution speed, reduced area consumption, and lower power dissipation, thanks to the hybrid CSA. Looking ahead, we plan to apply similar optimization techniques to all other arithmetic and logical blocks within the ALU. By optimizing these additional blocks using RTL optimization methods, we anticipate further reductions in area and power consumption while enhancing execution speed.

Future work will involve scaling the proposed ALU prototype to handle higher-bit operands, continuing to refine and improve the efficiency and performance of digital processors.

#### 5. Acknowledgement

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# 32. Modern comfort: The future of smart kitchen packaging

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#### Abstract

This paper demonstrates how IoT (Internet of Things) solutions can enhance the safety and functionality of home and commercial kitchens. The work focuses on creating an integrated system to address common hazards such as fire, smoke, and other risks that can lead to accidents or even loss of life. By employing various sensors and an IoT controller, the system enables users to monitor and control kitchen safety parameters (e.g., temperature, smoke levels, and sudden movements) in real time via their mobile devices. Users receive notifications when parameters exceed safe limits and can remotely activate additional safety equipment in the event of an accident. Control can be transferred as needed, ensuring that only authorized users have access. The mobile and IoT connections are facilitated through Wi-Fi or internet, allowing users to manage operations through an app that connects their mobile devices to the IoT system.

Keywords: Digital and Humidity Sensor, IR Sensor, MQ2 Sensor, Flame Sensor, IoT

#### 1. Introduction

Various works have been done on smart kitchen (Azran et al. 2017) for amenity and safety purposes. Projects regarding smart kitchens use IOT to monitor the level of gas in cylinder and send notification to supplier for refill automatically when gas in cylinder is exhausted (Palandurkar et al. 2020). For stressfree cooking, augmented reality (AR) technology is combined with computer vision (CV) technology that allows sensing of actual kitchen environment and producing a video tutorial of the chosen recipe (Gholse et al. 2021). Safety in kitchen can be maintained by using gas sensor which automatically turns off the gas knob when gas level is high (Vrishabh et al. 2021). It also includes monitoring the temperature and smoke level in the kitchen to prevent hazards (David et al. 2015). In Raspberry-pi based kitchen monitoring system, the LED will glow when the light intensity decreases and otherwise it will be off.

The gas level and pressure of kitchen will also be detected through different sensors. If gas level exceeds the threshold value, exhaust fan will be turned on. An email and an alert message will be sent via GSM network automatically (More et al. 2021). To get comfortable environment at home, user can set TV to his favourite channel, switch on-off lights and control A.C from his office desk. Even intrusion detection can be possible with the help of motion sensor and it can be controlled using smart phones (Pudugosula 2019; Thokal and Bogawar 2021).

In modern kitchens, ensuring the safety and convenience of all users, especially physically disabled and elderly individuals, is paramount. This paper introduces an innovative IoT-based solution designed to enhance kitchen safety and usability for these vulnerable groups. By integrating an IR sensor, the system automatically activates lights and an exhaust fan upon detecting human presence, providing immediate assistance without requiring manual intervention. Furthermore, a fire sensor is incorporated to enhance safety measures. Upon detecting fire, the system triggers an alarm, activates a sprinkler system to discharge water, and sends an alert message to the fire brigade. This comprehensive response occurs even if the kitchen door is closed, ensuring that all safety measures are executed automatically to prevent accidents and minimize potential harm. This work aims to provide a safer and more accessible kitchen environment, leveraging advanced technology to support the well-being of physically disabled and elderly individuals.

For the betterment of physically disabled and aged people, in this work, we have used IR sensor which will automatically switch on light and exhaust fan after detecting the presence of any human being inside the kitchen. Fire sensor attached with the system, will switch on the buzzer if it detects fire in the kitchen. The sprinkler will discharge water and an alert message will be sent to fire brigade. Even if the door is closed all-controlling actions will occur automatically which can prevent accidents.

#### 2. Methodology

To develop a robust IoT-based solution for enhancing kitchen safety and usability, we implemented a system composed of various sensors, a NodeMCU processor, and relays. The following methodology outlines the steps taken to design, build, and test this system.

System Design and Components are illustrated below.

i. System Architecture

The system architecture is depicted in Figure 1, illustrating the integration of sensors, the NodeMCU processor, and relays. The NodeMCU serves as the central processing unit, managing sensor data and establishing communication with Wi-Fi for remote monitoring and control.

ii. Sensors Employed

The system utilizes several sensors to monitor environmental variables:

IR Sensor: Detects human presence indirectly by sensing infrared radiation.

Gas Sensor (MQ2): An analog sensor that continuously measures gas concentration in the environment, capable of detecting sudden spikes in gas levels. DHT11 Sensor: Measures ambient temperature and humidity.

Fire Sensor:Detects radiation from fire breakouts, sending corresponding data to the processor.

iii. Relays

Relays with a range of 250 V and 10 amps are used to control high-power devices such as lights, exhaust fans, and sprinklers. These relays are triggered based on the sensor data processed by the NodeMCU.

#### Implementation

i. Sensor Integration

Each sensor is connected to the NodeMCU, which reads and processes the sensor data. The IR sensor detects human presence and activates the light and exhaust fan. The gas sensor continuously monitors gas levels and alerts the system in case of abnormal concentrations. The DHT11 sensor provides real-time temperature and humidity data. The fire sensor monitors for signs of fire and initiates emergency protocols if a fire is detected.

ii. Data Processing and Communication

The NodeMCU processes the incoming data from all sensors. It uses built-in Wi-Fi capabilities to communicate with a cloud server, enabling real-time data access and control through a mobile application. The processor evaluates the sensor data against predefined safety thresholds and triggers appropriate actions, such as activating relays to turn on devices or sending alert notifications.

iii. Control Mechanisms

The relays are controlled based on the processed sensor data. For instance, upon detecting human presence via the IR sensor, the NodeMCU activates the relays to switch on the light and exhaust fan. In the event of a fire, the fire sensor's data prompts the NodeMCU to trigger a buzzer, activate a water sprinkler, and send an alert message to the fire brigade. These actions are performed automatically, ensuring rapid response even if the kitchen door is closed.

iv. Remote Monitoring and Control

A mobile application interfaces with the system via Wi-Fi, allowing users to monitor realtime sensor data and control kitchen appliances remotely. This app provides notifications and alerts when sensor readings exceed safe limits, ensuring proactive management of potential hazards.

#### Testing and Validation

The system was tested in a controlled environment to validate its functionality. Each sensor's performance was evaluated to ensure accurate and reliable detection of environmental variables. The response time of the NodeMCU in processing data and activating relays was measured to confirm prompt action during emergency scenarios. The integration with the mobile application was also tested to verify seamless remote monitoring and control capabilities.

By implementing this methodology, we developed a comprehensive IoT-based kitchen safety system that enhances the safety and convenience of physically disabled and elderly individuals, ensuring a secure and responsive kitchen environment. In this paper, we have used various sensors to sense environment variables, processor (NodeMCU) which controls processing and build communication with Wi-Fi, and relays with the range of 250 V and 10 amps. Figure 1 shows the block diagram of the whole system. In the system we are using the following sensors: -

i. IR Sensor: For sensing human presence indirectly.

ii. Gas Sensor (MQ2): It is a analog sensor. Continuously measures gas concentration. It can also measure the higher spike of gas concentration at any instant.

iii. DHT11: It measures normal temperature and humidity.

iv. Fire Sensor: It can sense the radiation due to massive fire breakout and send the value to the processor.



Figure 1 System Block Diagram

We are utilizing a 4-channel relay module, with the following outputs assigned:

Channel 1: Default fan

Channel 2: Auxiliary fan, activated in case of excess gas or fire

Channel 3: Buzzer for fire alert

Channel 4: Default light

For the communication we are using Wi-Fi, this connects automatically to the bylink app and ubidots. We are using MQTT protocol in ubidots due to high reliability. When the person opens the door IR sensor senses and default fan and default light will be on. If the gas concentration is high, then Default fan and extra fan both will be on to remove the gas.

If a fire is detected, the system will automatically activate the default fan, the auxiliary fan, and the buzzer (relay output 3). This ensures that all necessary safety measures are taken even if the door is closed and one or more variables exceed safe limits.

Additionally, we can manually control three relay outputs using the Blynk app:

Default fan (Relay output 1)

Auxiliary fan (Relay output 2)

Default light (Relay output 4)

Relay output 3, which is dedicated to the fire alert buzzer, cannot be manually controlled to ensure it functions exclusively for emergency notifications.

#### 3. Workflow

We use a Wi-Fi-enabled NodeMCU microcontroller unit, which connects to Wi-Fi using an SSID and password, allowing information to be sent to or received from cloud systems. For measuring temperature and humidity, a DHT11 digital sensor is connected to one of the NodeMCU's digital pins, functioning as an input. An infrared sensor is used to indirectly detect the presence of a person. The output devices, which are controlled based on sensor inputs, can also be managed remotely.

To visualize the data graphically, we use the Ubidots IoT server. For monitoring and controlling the output devices, we employ the Blynk app service. Both the IoT device and the mobile or computer must be connected to the internet to enable this remote monitoring and control.

#### 4. Results and Discussions

The proposed IoT-based kitchen safety device was successfully installed in a household kitchen setting. The system architecture involves various sensors that collect data and send it to the NodeMCU microcontroller. The NodeMCU processes these inputs and transmits the data to the Ubidots IoT server, where it is presented in a graphical format.

This setup allows for real-time monitoring of critical parameters such as flame presence, humidity, temperature, and gas concentration. The data collected by the sensors are displayed on the Ubidots IoT server, enabling users to observe the values graphically. This graphical representation provides an intuitive way to monitor kitchen conditions. Users can access these values using a computer or mobile device, with the data also displayed on the serial monitor for immediate observation. Based on the readings, the system autonomously controls the output devices, turning them on or off as necessary to maintain safety.

The device is not limited to household kitchens but is also suitable for public buildings like hotels and eateries. The integration of IoT in kitchen automation significantly enhances the system's capability to protect against gas leaks, monitor temperature, and detect movement. This comprehensive approach ensures a safer kitchen environment by addressing multiple potential hazards.

All sensor data are stored on the server, which not only provides real-time monitoring but also maintains a log and status record of the system. This logging capability is crucial for tracking historical data and understanding the kitchen environment's conditions over time. The system is designed with predefined threshold values for each sensor. If any parameter exceeds its threshold, the system generates an alert and takes appropriate actions to mitigate the danger. For example, if gas concentration surpasses the safe limit, the auxiliary fan and buzzer are activated to ventilate the area and warn users of the danger.

The implemented IoT-based kitchen safety device demonstrates a robust solution for monitoring and controlling kitchen environments. By leveraging multiple sensors and the NodeMCU microcontroller, the system ensures real-time data collection, processing, and response. The use of the Ubidots IoT server for data visualization and the Blynk app for remote control enhances user interaction and monitoring capabilities. This system not only improves safety in household and public kitchens but also offers a scalable and adaptable solution for various other applications with potential enhancements and modifications.

#### 5. Conclusion

The implementation of our scaled-down IoTbased kitchen safety system demonstrates significant potential for enhancing safety and automation in household kitchens and various other environments. Through the integration of sensors, a NodeMCU microcontroller, and a 4-channel relay module, we have created a robust system capable of detecting and responding to environmental hazards such as fire, gas leaks, and abnormal temperature or humidity levels. The data collected from these sensors are processed and displayed on the Ubidots IoT server, providing users with real-time monitoring and graphical representation of kitchen conditions. The system's ability to automatically control output devices based on sensor inputs ensures that necessary actions are taken promptly to mitigate risks. For instance, in the event of a fire, the system activates the default and auxiliary fans, triggers the buzzer, and engages other safety mechanisms to minimize damage and alert users. The use of the Blynk app for remote monitoring and control adds a layer of convenience, allowing users to manage the system from their mobile devices.

In conclusion, the successful implementation of our scaled-down IoT-based kitchen safety system lays the foundation for a scalable, adaptable, and robust solution that can significantly enhance safety and automation in various environments. By leveraging advanced sensors, reliable microcontrollers, and real-time data processing, the system offers a comprehensive approach to monitoring and mitigating environmental hazards. Future upgrades and modifications will further expand its capabilities, making it suitable for a wide range of applications and ensuring that it meets the demands of more complex and largerscale deployments. The ongoing evolution of this system underscores the transformative potential of IoT technologies in creating safer, more efficient, and user-friendly environments.

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### 33. Predictive photo responsivity of FASnBr<sub>3</sub> using simulation

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#### Abstract

Today organic tin based perovskite solar cell is a new emerging technology. It has been proven by different experimental research that the best suited candidate of this group of perovskite is FASnI<sub>3</sub>. The experimental data of external quantum efficiency, integrated short circuit current density, photo responsivity is easily available in different research papers. This X site anion i.e iodine can be replaced by bromine (Br), chlorine (Cl) also but no such experimental data of the above said parameters of FASnX<sub>3</sub> (X = Cl, Br, I) is available in literature. Since bromine (Br) is placed just above iodine (I) in the same halogen group we believe that it may have some similarity in photo responsivity variation curve of FASnI<sub>3</sub> based solar cells. So, in this research we propose a photo responsivity variation.

#### 1. Introduction

Perovskite based solar cells are new emerging technology for solar cell. Among them tin based organic perovskite solar cells are very suitable candidate for research due to easy synthesis process and reasonably high photo conversion efficiency which is increasing day by day. Kojima et al first invented this perovskite based solar cell in 2009 having photo conversion efficiency 3.8% [1-5]. Since then photo conversion efficiency has been increased to more than 25% [9-17] by today. But this perovskites are lead (Pb) based which causes several environmental hazards. So, tin based organic perovskite based solar cells came to picture to replace the former perovskite based solar cell. After a huge research on tin based organic perovskite solar cell the photo conversion efficiency becomes 14% for FASnI, [2, 6-8]. The halogen iodine (I) can be replaced by other halogens. In this research paper we place X = Br as halogen so our perovskite becomes FASnBr<sub>2</sub>. Since there are no such research paper showing the variation of external quantum efficiency (EQE) and photo responsivity (R) with respect to frequency of incident light for FASnBr<sub>3</sub> we predict the above said variation by simulation.

#### 2. Methodology

It is known to us that for any semiconductor light absorption takes place only when the light energy  $E \ge$ , where is the band gap of the semiconductor. Otherwise it can be stated that if the frequency of the incident light  $f \ge$ , where is the cut off frequency of light absorption of that semiconductor then only absorption occurs otherwise this semiconductor will be acting as window layer for that semiconductor. So, if f <then EQE =  $\eta = 0$  and photo responsivity = R= 0.

Cut off frequency  $f_c$  can be written as , where h = Planck's constant. For FASnI<sub>3</sub> the  $E_g$  = 1.41 eV, & maximum value of EQE =  $\eta$  = 76% at f = 857 THz [2]. The variation of EQE is from 60% - 76% within the frequency range of 375 – 857 THz. EQE decreases sharply after 857 THz due to surface absorption. The algorithm of finding EQE of  $FASnI_3$  is given below.

- Step 1: Start.
- Step 2: Read the frequency in THz (*f*)

Step 3: Check if f,  $\eta = 0$ , then else if f < 375,  $\eta = 0.2$ , then else if f < 428.57,  $\eta = 0.7$ , thenelse if f < 858,  $\eta = 0.8$ , else  $\eta = 0.8 \exp(-100^{\circ}1e^{-5^{\circ}}f)$ .

Step 4: Stop.

For FASnBr<sub>3</sub> band gap = 2.55 ev [18–21]. So,  $f_c = 615.75$  THz.

• From the EQE of  $FASnI_3$  it is clear that after f > 900 THz the wavelength become so small that it will be absorbed totally within the surface.

• So, for higher value of *f* , the EQE and R will be sharply decreased.

As the electronegativity of Br is higher than I so for FASnBr<sub>3</sub>, η must be lesser than FASnI<sub>2</sub>.

This 100\*1e-5 is the fitting parameter for EQE vsf curve of FASnI<sub>3</sub>

#### 3. Result and Discussion



Figure 1: Frequency vs EQE plot of FASnI<sub>3</sub>





Figure 2: Frequency vs Responsivity plot of FASnI<sub>3</sub>



Figure 3: Frequency vs EQE (theoretical) plot of FASnBr<sub>3</sub>



Figure 4: Frequency vs Responsivity (theoretical) plot of FASnBr<sub>3</sub>

Figure 1 shows the variation of EQE w.r.t frequency of incident light of FASnI<sub>3</sub>for theoretical and practical both cases. Practical data of EQE w.r.t frequency variation of FASnI<sub>3</sub> is available in literature. From the formula R = , we get the required photo responsivity value (R). In this case  $q = 1.6*10^{-19}$  Coulomb. Figure 2 shows the frequency vs Responsivity plot of FASnI<sub>3</sub> both theoretical & practical case.

In case of FASnBr<sub>3</sub>, = 2.55 ev,  $f_c$ = 615.75 THz. The frequency vs EQE (theoretical) plot of FASnBr<sub>3</sub> is given here in Figure 3 by applying the above mentioned alogorithm with revised parametric values. The values of photo responsivity (R) is obtained by the above mentioned formula and plotted w.r.t frequency of the incident light. (Figure 4).

#### 4. Conclusion

The predicted external quantum efficiency (EQE) and photo responsivity (R) curve of FASnBr<sub>3</sub> has been plotted here. It will help us

for further study related to FASnBr<sub>3</sub> based perovskite solar cell.

The authors are also declare that there are no conflict of interest among them and others.

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### 34. Effect of electronegativity and size of X site halogen on the band gap of $MASnX_3$ (X = Cl, Br, I) perovskites

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#### Abstract:

Perovskite based solar cells (PSC) are latest growing technology. This field is rapidly growing today due to easy synthesis process, low cost and rapid increment of photo conversion efficiency. In PSC the lead (Pb) based PSC were the first invented solar cells. Due to the toxicity of lead (Pb) it is replaced by another element tin (Sn) of the same group of the periodic table. In this PSC the organic tin halide based PSC are the new emerging technology. One of the important organic tin based perovskite material is MASnX<sub>3</sub>, where X= Cl, Br, I and MA is methylammonium. In this research paper the mathematical expression is derived to show the effect of electronegativity and size of X site halogen or size of anion on the band gap of MASnX<sub>3</sub>.

#### 1. Introduction

Perovskite based solar cells (PSC) are the new type of solar cell which are increasing nowadays. PSC are invented in 2009 by Kojima et al. and at that time the photo conversion efficiency (PCE) of PSC was about 3.8% but today it is more than 25%. At first the PSCs were based on lead (Pb) but lead causes different types of hazards in human body including environmental hazards. For this reason lead (Pb) is replaced by tin (Sn). Tin is another member of the same group of periodic table. Tin based PSCs have lower PCE in comparing to lead based PSC but the former is eco friendly. Fang et al [1] suggest that formamidinium tin triiodide has the ability to cross the Shockley limit among all tin based PSC. Zhu et al. [2] shows that the PCE of FASnI, increases to 14%. The performance of PSC are measured either by software simulation like using SCAPS 1D simulator [3-5] or by characterizing the fabricated device [6-8]. The research papers on SCAPS 1D simulation are showing the graphical depiction of variation or change of different solar cell parameters like  $V_{OC}$  (open circuit voltage),  $J_{SC}$  (short circuit current density), PCE (photo conversion efficiency), FF (fill factor) with respect to thickness of LHL (light harvesting layer that is thickness of perovskite layer), doping concentration etc. based on the poisson's equation, continuity equation & charge transport equation. The general form of any perovskite material is written as ABX<sub>3</sub> [9 -10]. Where A, B are cataions and X is anion. For tin (Sn) basedorganic metallic perovskite the A is methylammonium (MA) or formamidinium (FA), B is tin (Sn) and X is halogens like chlorine (Cl), bromine (Br), iodine (I). The structure of perovskite material may be cubic or orthorhombic etc. [11-13]. For cubic structure the value of tolerance factor (t) is within 0.89 to 1 and the lower t values give less symmetric tetragonal or orthorhombic structures. For
halide perovskite the range of t is given as 0.89 < t < 1.11 and  $\mu$  is octahedral factor. For halide perovskite the range of  $\mu$  is given as 0.44 <  $\mu$  < 0.9 [14-16]. Band gap is a very significant and crucial parameter of solar cell material. For tin based organic solar cell one of the important material is MASnX<sub>3</sub>, where X = Cl, Br, I. In this research paper the numerical relationship among the band gap of MASnX<sub>3</sub> and electronegativity, size of X site halogen anion is established.

Table 1: List of different parameters of MASnX<sub>3</sub>.

#### 2. Methodology

In tin (Sn) based organic metallichalide perovskite the organic radicals are Methylammonium (MA) (CH<sub>3</sub>NH<sub>3</sub>), Formamidinium (FA) (NH<sub>2</sub>CHNH<sub>2</sub>), Ethylammonium (EA) (CH<sub>3</sub>CH<sub>2</sub>NH<sub>3</sub>) etc. but in this research paper we only discuss about the band gap dependence of MASnX<sub>3</sub> on electronegativity, size of X site halogen anion. The electronegativity values of X site halide anion and other parameters are given below [17–29] in Table 1 in Pauling scale.

A site cation name (nm)	Name of perovskite	Band gap $E_g(ev)$	X site halogen name	Electronegativity value of X site halogen (Pauling scale)	Size of X site halogen in nm (
Methylammonium (MA)	MASnCl <sub>3</sub>	2.8	Chlorine (Cl)	3	0.181
$R_{A} = 0.18$	MASnBr <sub>3</sub>	2.15	Bromine (Br)	2.8	0.196
	MASnI <sub>3</sub>	1.25	Iodine (I)	2.5	0.220

Considering the data from table 5-6 taking band gap ( $E_g$ ) of MASnX<sub>3</sub> as a dependent parameter and electronegativity and size of X site halogen anion as independent parameter using numerical method of least square of curve fitting we obtain the mathematical expression relating them.

The numerical equations involving band gap  $(E_g)$  and halogen anions electronegativity  $(\chi)$  is given below using method of least square of curve fitting.

$$E_g = -4.44 + 2.352\chi$$
 (i)

$$E_{p} = -3.0583 + 0.4899\chi + 0.48952\chi^{2}$$
(ii)

Equations (i), (ii) is for linear& quadratic fitting curve respectively.

Similarly, the numerical equations involving the size of anion in nm  $(R_x)$  and band gap  $(E_g)$  is given below by using method of least square of curve fitting.

$$E_g = 10.025 - 39.9921 R_X$$
 (iii)

$$E_g = 4.5064 + 18.2133 R_X - 152.1791 R_X^2$$
 (iv)

Equations (iii), (iv) is for linear and quadratic fitting curve respectively.

#### 3. Result and Discussion

Based on the result of equation (i), (ii) and Table 1 the Table 2 is prepared and given below.

Table 2:	List of different curve fitting values of
band gap	o of MASnX <sub>3</sub> depending on halide anions
electrone	gativity.

Anion (X)	Electro- negativity (χ)	Linear fit value of $(E_g)$	Quadratic fit value of $(E_g)$ (ev)	Actual $(E_g)$ (ev)
Cl	3	2.616	2.817	2.8
Br	2.8	2.1456	2.151	2.15
Ι	2.5	1.44	1.225	1.25

From the above mentioned data of Table 2 it is clear that the result of quadratic fitting curve is much nearer comparing to the linear fitting curve result. So, we accept the equation (ii) i.e quadratic fit equation as derived using before mentioned numerical process. The graphical representation of linear fit, quadratic fit and actual value of vs halogen electronegativity is plotted and given below.



**Figure 1:** Halogen anions electronegativity vs band gap of MASnX<sub>3</sub> plot.

Figure 1 depicts the electronegativity of halogens vs band gap curve. In this curve it is clearly visible that band gap of MASnX<sub>3</sub> perovskites are strongly dependent on theelectronegativity of the halogen elements (X = Cl, Br, I) and as electronegativity ( $\chi$ ) increases the corresponding band gap ( $E_g$ ) of perovskites are increasing. The non linear relationship between halogen electronegativity ( $\chi$ ) and perovskite band gap ( $E_g$ ) can be written as

$$E_g = -3.0583 + 0.4899\chi + 0.4899\chi^2$$

Which is the derived quadratic fit curve establishing the numerical relationship between different halogen anions electronegativity ( $\chi$ ) and band gap ( $E_e$ ) of MASnX<sub>3</sub> perovskites.

Similarly, based on equation (iii), (iv) and Tables 2 the Table 3 is prepared and given below.

Table 3: List of different curve fitting values of band gap values of MASnX<sub>3</sub> depending on size of halide anions.

Anion (X)	Size of anion $(R_x)$ (nm)	Linear fit value of $(E_{\alpha})$ (ev)	Quadratic fit value of $(E_{a})$ (ev)	Actual $(E_g)$ (ev)
Cl	0.181	2.786	2.817	2.8
Br	0.196	2.186	2.23	2.15
Ι	0.220	1.226	1.147	1.25

From the data of Table 3 it is evident that the linear fit curve i.e., equation (iii) is much nearer value therefore we accept the linear fit curve i.e., equation (iii). So, the accepted equation which numerically established the relation between halogen anion size and band gap of MASnX<sub>3</sub> is

The graphical representation of linear fit, quadratic fit and actual value of vs halogen anion size  $(R_x)$  in nm is given below.

Figure 2 shows the size of halogen atom  $(R_x)$  vs band gap  $(E_g)$  plot. In this plot we can clearly see that as the size of halogen atom increases the band gaps of MASnX3 is decreases. So from that Figure 2 we can also observe that the relation between halogen atom size  $(R_x)$  and MASnX3 band gap  $(E_g)$  is almost linear. So, we can approximately say that  $R_x \alpha \frac{1}{E_g}$  i.e size of halogen atom is inversely proportional to the band gap of MASnX3 perovskites and this is established here numerically having a negative slope of equation (iii).

Size of halogen anions vs Band gap of MASnX<sub>3</sub>



Figure 2: Size of halogen anion vs band gap plot of MASnX<sub>3</sub>

# 4. Conclusion

In this research paper the band gap dependence of MASnX<sub>3</sub> on X site halogen element size, electronegativity is shown. It concludes as the band gap of MASnX<sub>3</sub> increases as the halogen anion's electronegativity increases and the band gap dependence on halogen anion electronegativity is non linear quadratic function. It also shows that the band gap of MASnX<sub>3</sub> is inversely proportional with the size of halogen atom and the numerical relationship between them is linear with a negative slope.

There is no conflict of interest among authors and others.

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# 35. Influence of A site cation and X site halogen anion on the band gap of ASnX<sub>3</sub> (A= MA, FA) perovskites

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#### Abstract

Perovskite based solar cell (PSC) are the new emerging solar cell technology. Among these PSC the latest research thrust is on tin based solar cell due to the environmental issue related of lead based solar cell. The organo metallic halide perovskites are the best choice for PSC due to their low cost and uncomplicated synthesis process which requires less number of laboratory equipments. The effect of A site cation and X site anion (halogen element) on the band gap of perovskite material is very important. In this research paper authors show the relationship of band gap with respect to the size, electronegativity of the anion (halogen element) and the size of the A site cation for tin based organo metallic halide perovskites. The findings clearly pointed out that the band gap of a tin based organo metallic halide perovskite is proportional to the size of X site anion (halogen element). In this research methylammonium (MA), formamidinium (FA) is taken as A site organic cation.

#### 1. Introduction

Perovskite based solar cells (PSC) are the new type of solar cell which are increasing day by day. PSC are invented in 2009 by Kojima et al. and at that time the photo conversion efficiency (PCE) of PSC was about 3.8% but today it is more than 25%. At first the PSCs were based on lead but lead causes different types of hazards in human body including environmental hazards. For this reason lead (Pb) is replaced by tin (Sn). Tin based PSCs have lower PCE in comparing to lead based PSC but the former is eco friendly. Fang et al. [1] suggest that formamidinium tin triiodide has the ability to cross the Shockley limit among all tin based PSC. Zhu et al. [2] shows that the PCE of FASnI, increases to 14%. The performance of PSC are done either by software simulation like using SCAPS 1D simulator

[3-5] or by characterizing the fabricated device [6-8]. The research papers on SCAPS 1D simulation are showing the graphical depiction of variation or change of different solar cell parameters like  $V_{OC}$  (open circuit voltage),  $J_{SC}$  (short circuit current density), PCE (photo conversion efficiency), FF (fill factor) with respect to thickness of LHL (light harvesting layer i.e. thickness of perovskite layer), doping concentration etc. based on the poisson's equation, continuity equation & charge transport equation.

Band gap is a very important parameter of solar cell material. For tin (Sn) based organo metallic halide perovskite the organic radical (A site cation) and halide material (X site halogen) has significant role in formation of band gap because tin (Sn) (B site cation) is a metal which has no contribution in formation of band gap. In this research paper the dependence of band gap

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of perovskite on size of A site cation, X site anion, electronegativity of X site anion is depicted.

# 2. Methodology

The general form of any perovskite material is expressed as  $ABX_3$  [9 -10]. Where A, B are cataions and X is anion. For tin (Sn) based organo metallic perovskite the A is methylammonium (MA) or formamidinium (FA), B is tin (Sn) and X is halogens like chlorine (Cl), bromine (Br), iodine (I). The structure of perovskite material may be cubic or orthorhombic etc. [11-13]. For cubic structure the value of tolerance factor (t) is in between 0.89 to 1 i.e 0.89 < t < 1 and the lower t values give less symmetric tetragonal or orthorhombic structures. The tolerance factor (t) is given as

Where are the radii of A site, B site cations and X site anion. For halide perovskite the range of t is given as 0.89 < t < 1.11 and , where  $\mu$  is octahedral factor. For halide perovskite the range of  $\mu$  is given as  $0.44 < \mu < 0.9[14 - 16]$ .

In tin (Sn) based organo metallic halide perovskite the organic radicals are methylammonium (MA) (CH<sub>3</sub>NH<sub>3</sub>), formamidinium (FA) (NH<sub>2</sub>CHNH<sub>2</sub>), ethylammonium (EA) (CH<sub>3</sub>CH<sub>2</sub>NH<sub>3</sub>) etc. but generally methylammonium (MA) and formamidinium (FA) are used. For X site halide anion X = Cl, Br and I are used.

A site cation name	Name of perovskite	Band gap $(E_g)(ev)$	X site halogen name	Electronegativity value of X site halogen (Pauling scale)	Size of X site halogen in nm $(R_{\chi})$
Methylammonium (MA)	MASnCl <sub>3</sub>	2.8	Chlorine (Cl)	3	0.181
Size in nm = $0.18$	MASnBr <sub>3</sub>	2.15	Bromine (Br)	2.8	0.196
	MASnI <sub>3</sub>	1.25	Iodine (I)	2.5	0.220

Table 1: List of different parameters of MASnX<sub>3</sub>.

Table 2: List of different parameters of FASnX<sub>3</sub>.

A site cation name	Name of perovskite	Band gap $(E_g)(ev)$	X site halogen name	Electronegativity value of X site halogen (Pauling scale)	Size of X site halogen in nm $(R_X)$
Formamidinium (FA)	FASnCl <sub>3</sub>		Chlorine (Cl)	3	0.181
Size in nm = $0.253$	FASnBr <sub>3</sub>	2.55	Bromine (Br)	2.8	0.196
	FASnI <sub>3</sub>	1.41	Iodine (I)	2.5	0.220

[17-30].

From the above mentioned Table 1 and Table 2 the dependence of band gap  $(E_g)$  of MASnX<sub>3</sub> and FASnX<sub>3</sub> over halogen element's electronegativity ( $\chi$ ), size of halogen element

 $(R_x)$  is plotted in Figures 1,2 respectively. The dependence of A site cations i.e MA and FA over band gaps of MASnX<sub>3</sub> and FASnX<sub>3</sub> is depicted in Figure 3.

#### 3. Result and Discussion



**Figure 1:** Electronegativity of halogens vs band gap plot of MASnX<sub>3</sub> and FASnX<sub>3</sub>



**Figure 2:** Size of halide vs band gap plot of MASnX<sub>3</sub> and FASnX<sub>3</sub>



Figure 3: Size A site cation vs band gap plot of  $\rm MASnX_3$  and  $\rm FASnX_3$ 

Figure 1 depicts the electronegativity of halogens vs band gap curve. In this curve it is clearly visible that band gap of MASnX<sub>3</sub> and FASnX<sub>3</sub> perovskites are strongly dependent on the electronegativity of the halogen elements (X = Cl, Br, I) and as electronegativity ( $\chi$ ) increases the corresponding band gaps ( $E_g$ ) of perovskites are increasing. The relationship between halogen electronegativity ( $\chi$ ) and perovskite band gap ( $E_g$ ) can be written as  $\chi \alpha$ .

That is  $\chi$  is proportional to . Figure 1 shows almost linear relationship between halogen electronegativity ( $\chi$ ) and perovskite band gap ( $E_{\alpha}$ ).

Figure 2 shows the size of halogen atom (vs band gap (plot. In this plot we can clearly see that as the size of halogen atom increases the band gaps of MASnX<sub>3</sub> and FASnX<sub>3</sub> is decreases. So from that Figure 2 we can also observe that the relation between halogen atom size ( and MASnX<sub>3</sub>, FASnX<sub>3</sub> band gap ( is almost linear. So, we can

approximately say that  $\alpha$  i.e size of halogen atom is inversely proportional to the band gap of MASnX<sub>3</sub> and FASnX<sub>3</sub> perovskites.

Figure 3 shows the plot of size of A site cation, which is a organic radical vs band gap of I based, Br based and Cl based organo metallic perovskites i.e MASnX<sub>3</sub> and FASnX<sub>3</sub>. The band gap of FASnCl<sub>3</sub> is not plotted here as it is unavailable in literature.

From that plot we can see that as the size of A cation increases from methylammonium (MA) to formamidinium (FA) the band gap increases for Br

based and I based tin based organo metallic perovskites i.e MASnX<sub>3</sub> and FASnX<sub>3</sub>. The slope of the plot is more in Br based perovskites comparing to I based perovskites. It indicates that for the Br based organo metallic perovskites the effect of size of the A site organic radical is much more than I based organo metallic perovskites. This result is expected because the metallic nature is more in iodine (I) rather than bromine (Br) as iodine situated just below the bromine in Gr 17 of modern periodic table. So, for I, Sn based organo metallic perovskites the effect of A site cation size on band gap is lesser comparing to Br, Sn based organo metallic perovskites. From Figure 3 we can approximately say that  $\alpha$  i.e size of A site cation is proportional to the band gap of tin based organic halide perovskites.

# 4. Conclusion

In this research paper the band gap dependence of tin based organic halide perovskite i.e. MASnX<sub>3</sub> and FASnX<sub>3</sub> on X site halogen element size, electronegativity and A site cation size is shown.

It concludes as the band gap of tin based organic halide perovskites i.e. MASnX3 and FASnX3 is proportional to halogen elements electronegativity, size of A site cation and inversely proportional with the size of halogen atom.

There is no conflict of interest among authors and others.

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# 36. Predicting congestive heart disease using machine learning algorithms on dual dataset

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#### Abstract:

The heart, a vital organ in the human body, is susceptible to various irregularities known as cardiovascular diseases (CVDs), affecting both the heart and blood vessels. An approximated 17.9 million individuals succumbed to CVDs in 2019 alone based on the data collected from World Health Organization (WHO). In the healthcare sector, machine learning has emerged as a valuable tool for the early detection of such diseases. In this context, we have employed several machine learning algorithms: Support Vector Machine (SVM), K-Nearest Neighbors (KNN), and Random Forest (RF), to predict the occurrence of heart disease. We have employed the benchmark dataset of UCI for heart disease prediction. Here, we have considered two types of dateset: UT1 and UT2 for variations. It consists of 13 different heart disease-related parameters. It has been observed from the MATLAB results that RF gives maximum accuracy: 83.70% and 88.90% for UT1 and UT2 dataset respectively, compared to the other algorithms SVM and KNN. Then we have justified the results with Weka software for RF algorithm which gives accuracy 82% and 83% for UT1 and UT2 dataset respectively. Therefore, this model can be useful for early prediction of heart disease leading to a tool of decision support system for the medical practitioners.

#### 1. Introduction

The heart stands as the paramount and indispensable organ within the body. Recently, heart diseases have emerged as one of the most pressing health concerns. Among these, cardiovascular disease (CVD) takes the forefront as the leading cause of mortality worldwide. In 2019 alone, an estimated 17.9 million individuals succumbed to CVDs, constituting approximately 32% of all global deaths (www.who.int). Heart attack is not restricted to the old age people only. Nowadays, younger people are also get effected by the heart attacks. Therefore, early detection of irregularities related to heart can be very much important to mankind. This can be done with the help of supervised machine learning models based on various classifier based algorithms.

Symptoms and physical problems of the patient are typically included in the medical dataset. Machine learning (ML) has surfaced in recent times as a pioneering approach for health-care forecasting and diagnosis that can categorize medical data into specific class labels, such as sick or non-sick (Yoo et al. 2017). A successful use of ML for improved diagnostic effectiveness and efficiency has been made possible by different methods (Richter and Khoshgoftaar 2018). Different extracted features can give an optimal assessment by using variety of ML models, including Decision Tree (DT), SVM, RF, and others.

In a recent report (Dou and Meng 2023), a comparative analysis has been done using different machine learning algorithms on medical dataset. They utilized Weka-based classification on four distinct datasets: mammographic mass dataset, Indian liver disease patient dataset, delivery cardiotocography dataset, and lymphatic tractography dataset. Baitharu et al. Made a comparison of data classification accuracy using liver disorder data under different circumstances. The study quantitatively compared the predictive performances of well-known classifiers (Baitharu, Pani 2016). However, they have not studied the human heart conditions. Shetgaonkar and Aswale have reported various Artificial Intelligence (AI) based methods such as DT, Naïve Bayes, & Neural Network for detecting the heart diseases. Then, the accuracy of each method would be compared based on various parameters (Shetgaonkar and Aswale 2021). Sharma et al. have done the heart disease prediction using machine learning techniques such as Random Forest, Support Vector Machine, Naive Bayes and Decision tree. They have examined that random forest is the most efficient algorithm for decision making (Sharma et al. 2020). Bharti et al. have proposed a work where they have predicted heart dis- ease with the combination of ML and deep learning (DL) (Bharti et al. 2021). Ahmed et al. described a machine learning approach for enhancing the disease prediction. They developed a machine learning model to improve the accuracy. By using this model, they can predict the diseases like heart failure (Ahmed et al. 2022). Beunza et al. predicted the risk of heart related problem using different machine learning algorithms. Not only that, they also compared the results with two different statistical software platforms (Beunza et al. 2019).

The reports have been discussed so far are based on the machine learning approaches. Most of the researchers are used single software platform for classifying the given dataset. Here, we have proposed a model where the heart disease data have been analyzed on two dataset collected from two different sources. We have tested various ML algorithms such as: SVM, KNN and RF for heart disease prediction by using MATLAB software. Then, the results have been compared with another data mining software Weka.

#### 2. Materials

This section represents the method of this research work. There are no apparent limitations in the dataset with uneven distributions. The dataset consists of a significant number of noisy values. These dataset are needed to be pre-processed to handle the noisy values. The pre-processing stage includes several stages: data cleaning, outlier removal and feature selection. The proposed model is utilized on two different dataset of UCI (archive.ics.uci.edu), namely UT1 and UT2.

The cardiovascular dataset is utilized by two labels, i.e., positive and negative. Negative data represents the healthy volunteer and positive data specifies diseased person. This work presents three different automated ML methods to predict and classify heart disease. Figure 1 represents the flow of the work. It includes stages of data collection, model training, testing, and comparing outcomes. The dataset is divided into two parts as training and testing part with 70% and 30% respectively. The machine learning methods are discussed below.



Figure 1. Flow of the research work

#### 2.1 Support Vector Machine (SVM)

SVM is a supervised classification method which can be utilized to find the results for different regression and classification tasks. The SVM algorithm is designed to create an optimal decision boundary, also known as a hyperplane, within an n-dimensional space to effectively classify data points. This hyperplane serves to separate the different classes of data. SVM achieves this by identifying the extreme points and vectors to construct the hyperplane. The SVM classifier relies on identifying support vectors, which represent extreme instances within the dataset. While SVM is commonly recognized for its superior performance compared to other classifiers, its primary advantage lies in its ability to handle non-linearly separable data. In such cases, SVM with a non-linear kernel, such as the Radial Basis Function (RBF), is deemed appropriate.

#### 2.2 k-Nearest Neighbour (kNN)

Embarking on an exploration of avant-garde solutions for k-NN is one of the easiest Supervised Learning ML technique, which assumes the similarity between the new data points into the category that is most similar to the existing classes. This can also be used for regression as well as classification. This non-parametric algorithm does not make any assumption on underlying data.

#### 2.3 Random Forest (RF)

The RF classifier is also a supervised ML based classifier which helps to design a model using decision tree. This is generally used for labeling the abnormal data by collecting the bias and minor differences.

#### 2.4 Performance Measure

The classification is analyzed by some statistical methods are described below:

True Positive Rate (TPR): The fraction of diseased cases predicted as diseased.

$$True Positive Rate = \frac{TP}{TP + FN}$$
(1)

**Specificity:** The fraction of normal cases predicted as normal one.

$$Specificity = \frac{TP}{TP + FN}$$
(2)

**Precision:** The fraction of truly diseased cases from all cases the model predicted as diseased.

$$Precision = \frac{TP}{TP + FN}$$
(3)

Accuracy: The fraction of cases the model correctly identified.

Accuracy = 
$$\frac{TP + TN}{TP + TN + FP + FN}$$
 (4)

Where, True Positive (TP): Predicted diseased, actual diseased, False Positive (FP): Predicted diseased, actual non-diseased, False Negative (FN): Predicted non-diseased, actual diseased, True Negative (TN): Predicted non-diseased, actual non-diseased. These parameters are graphically represented in Figure 2.

**ROC curves and AUC values.** The receiver operation characteristics (ROC) curve demonstrates how well a classification model performs across all thresholds for classification. The curve represents the plot of sensitivity vs. (1-specificity). The area under the ROC curve (AUC) quantifies the complete two-dimensional space beneath the ROC curve



Figure 2 Confusion matrix illustration with TP, TN, FP and FN  $\,$ 

	Table 1	Table 1. Classification performance of two different dataset using three machine learning algorithms.								
Classifiers	UT1 Dataset				UT2 D	UT2 Dataset				
	TPR	Specificity	Precision	Accuracy	AUC	TPR	Specificity	Precision	Accuracy	AUC
	(%)	(%)	(%)	(%)		(%)	(%)	(%)	(%)	
SVM	80	74.60	72.22	82.30	0.76	87.30	83.65	87.30	84.4	0.89
kNN	79.30	76.30	79.20	83	0.89	94	81.60	93.80	85	0.90
RF	86	83.40	86	83.70	0.90	84	78.25	84.02	88.9	0.87

#### 3. Results and Discussions

For the analysis of the dataset, we have used three different ML techniques such as: SVM, KNN and RF. Here, we have used a benchmark dataset of UCI for heart dis- ease prediction. It consists of 13 different heart disease-related parameters. We have done a comparative study between UT1 and UT2 dataset that has been depicted in Figure 3. It has been observed from the Figure 3 that RF exhibits higher TPR for UT1 dataset and kNN shows the higher TPR for UT2 dataset compared to other classifiers. As shown in Table 1, various machine learning classifiers, such as SVM, KNN and RF have been applied on the CVD dataset. The results indicate that, RF algorithm shows the higher accuracy of 83.70% along with specificity of 83.40 %, and precision of 86 % for UT1 dataset. In case of UT2 dataset, accuracy (88.9 %) is higher for RF algorithm whereas kNN shows the higher specificity and precision compared to other algorithm. Figure 4 shows that the ROC curves of three different classifiers along with AUC values. It has been observed from the Figure 4 that AUC value is more in RF algorithm for UT1 dataset. But, kNN algorithm exhibits higher AUC value for UT2. Thus, the classifier based analysis can be done for prediction of heart disease. The results are also compared by using Weka software, from which we have obtained the accuracy of 82% and 83% for the RF algorithm, for the UT1 and the UT2 datasets, respectively. Therefore, the results have justified by two different software.

### 4. Conclusion

In this paper, we have attempted to analyze the three different ML algorithms for early prediction of heart disease. Results shows that RF gives the greater accuracy: 83.70% and 88.9% compared to other algorithms for both the dataset: UT1 and UT2 respectively, collected from UCI. Thus, this algorithm can be helpful to the medical practitioner as a decision support system for early detection of CVD. The obtained results are also verified by other software named Weka. In near future, we may collect the dataset from local clinic for validation.



**Figure 3.** Confusion matrix of three different classifiers (left column: UT1 Dataset; right column: UT2 Dataset): (a and d) SVM classifier, (b and e) kNN classifier and (c and f) RF classifier respectively.



Figure 4. ROC curves of three different classifiers along with AUC values (left column: UT1 Dataset; right column: UT2 Dataset): (a and d) SVM classifier, (b and e) kNN classifier and (c and f) RF classifier respectively.

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# 37. A computational investigation of FeAsn (n=1-4) clusters using DFT-based descriptors

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#### Abstract

A study on FeAsn (n=1-4) clusters was conducted using Density Functional Theory (DFT) due to its relevance in superconductors. Geometry optimization was carried out with the B3LYP exchange-correlation functional and the LANL2DZ basis set. The calculated bond lengths and global descriptors, such as molecular hardness, softness, electronegativity, and electrophilicity index, for the most stable cluster configurations align well with experimental values. The findings indicate that all clusters exhibit a substantial highest occupied molecular orbital (HOMO) to lowest unoccupied molecular orbital (LUMO) gap, suggesting their strong potential for superconductivity applications.

Keywords: Density Functional Theory; As-Fe; HOMO-LUMO Energy Gap; Superconductors.

# 1. Introduction

Superconductivity has attracted various interest in recent days especially in the domain of solid-state physics [1]. The primary areas of focus in superconductivity research are investigating materials with high critical temperatures and uncovering the mechanisms behind superconducting electron pairs. [1]. The discovery of superconductivity in rare earth oxypnictides compounds have inspired researchers. Johnson et al. [2] reported the superconductivity of quaternary ZrCuSiAs compound, which paved the way for all further research. Compounds with rich chemical compositions were synthesized, that exhibited a range of electronic properties like ferromagnetism, antiferromagnetism, semi conductivity, superconductivity etc. [3-12].

Kamihara et al. [13] were the first to discover superconductivity in LaFePO at relatively low critical temperature. Initially experimental research was performed based of clusters containing elements exhibiting superconductivity [14-17]. Arsenic based superconductors have been reported with doping of other elements, which enhance their properties [18-23]. Katayama et al. [18] reported the superconductivity of Ca1-xLaxFeAs2. Their single-crystal X-ray diffraction analysis showed that crystallization occurred within clusters arranged in zigzag chains, resulting in monoclinic structures. Yakita et al. [19] performed a study on CaFeAs2 and PrFeAs2 where they studied the magnetization along with resistivity measurements of the clusters. The clusters unveiled superconductivity mutually in magnetization and resistivity measurements. Kudo et al. [20] reported a huge variation in critical temperature with phosphorus and antimony doping of Ca1-xLaxFeAs2,

tin doping the same cluster, the crystals were fabricated experimentally, and X-ray diffraction helped in analysis of the crystals. Kudo et al. [21] studied the increase in critical temperature of 112 phases of Ca1–xRExFeAs2 and observed the variation of critical temperature is greater for La doped clusters than for Pr and Nd doped samples. Bert et al. [22] reported the structural properties of GaAs, in which arenic cluster size is established attributing to superconducting phase.

Similarly, iron doped superconductors, which are also considered high temperature superconductors, were first reported by Gordon et al. [24]. These new materials offered scholars a new perspective of these superconductors, yet also furnished variable innovative concepts for scrutinizing the superconductivity contrivances, comprising antiferromagnetic variations [25] designated in form of a spin density wave [25], pseudo gap [26], and three-band theory [27]. The Bardeen-Cooper-Schrieffer (BCS) theory was the first to describe superconductivity as a microscopic phenomenon resulting from the condensation of Cooper pairs [28]. Although iron atoms possess unpaired electrons in their outer orbitals, they remain aligned with each other [29]. While iron is a good conductor, it remains unclear how it could achieve zero-resistance superconductivity at high temperatures without the strong interactions that create a correlated insulating state in copper-based materials [29]. As a result, "Fe-based superconductors" cannot be clarified by Bardeen-Cooper-Schrieffer theory or BCS theory, and are consequently termed as unconventional superconductors [30, 31].

Experimental evidence indicates that Fe-Asbased superconductors have a significantly higher critical temperature compared to other types. Moreover, only specific Fe-As-based superconductors have demonstrated a high critical temperature exceeding 40 K [21]. Theoretical studies have shown that some arsenic based super-conductors exhibit similar electronic band structures [32]. The focus of our study is thus based on Fe-As based clusters, the properties of their optimized structures and their prospects. This report has been presented in such a way that Section 2 provides a brief account of the computational methodology. Additionally, the subsequent sections provides the computational results along with the corresponding discussions. The entirety of the study has been briefed in section 4.

#### 2. Computational Details

Numerous fields of study like alloy based clusters, fluid mechanics, molecular and nuclear physics, life sciences etc. has adopted this technique [33-38]. DFT methods is successfully used in various cases [39-42]. In the past few years, our group has executed various analysis on metallic clusters [43-49] based on DFT.

In this report a theoretical investigation based on different nanoclusters, FeAsn (n=1-4) has been conducted. Optimization of the clusters have been instigated by means of Gaussian 16 [50] using DFT framework. The hybrid functional parameter (B3LYP) aided by basis set LANL2DZ has been opted and intended for orientational optimization.

Ionization Energy (I) in addition to Electron Affinity (A) of all the clusters are estimated via the subsequent equations [51]:

- $I = \varepsilon HOMO$
- $A = \varepsilon LUMO$

By means of values of 'I' and 'A', which are the conceptual descriptors namely molecular hardness ( $\eta$ ), molecular softness (S), electro-negativity ( $\chi$ ) and electro-philicity index ( $\omega$ ) are worked out. The equations based on which computation have been performed have been presented in equation (iii) to equation (vi) -

$$\chi = -\mu = \frac{I+A}{2} \tag{iii}$$

Here,  $\boldsymbol{\mu}$  implies the chemical potential of the cluster.

$$\eta = \frac{I - A}{2} \tag{iv}$$

$$S = \frac{1}{2\eta} \tag{v}$$

$$\omega = \frac{\mu^2}{2\eta} \tag{vi}$$

#### 3. Results and Discussion

#### 3.1 Equilibrium Geometry



Figure 1: Lowest energy structures of FeAsn (n=1-4)

The ground state or least energy structures of FeAsn (n=1-4) has been presented in Figure 1, along with the point groups and spin multiplicity. The figure also shows the bond lengths between all the atoms in every structure. Bond length is elucidated as the shortest path between the centres of atoms that are bonded. The dimension of the bond is confirmed using the aggregate value of bonded electrons. The increase in the magnitude of bond order, leads to the resilient attraction between the two atoms and results in smaller magnitude of bond length. Over all, the measurement of the bond amid two atoms is almost equivalent to the summation of the covalent radii of the concerned atoms. Bond length is represented in Angstrom (Å).

FeAs displays ground state configuration is a linear structure presented in 1-a with As atom linked in a line with Fe atom. The orientation has the symmetry group  $C \propto V$  and doublet spin multiplicity. The bond length of As-Fe is 2.370Å.

FeAs2 has the ground state structure, presented in 1-b, which has Fe placed at one of the ends. The structure comprises of point group of CS with triplet spin multiplicity. The bond length of As-As is 2.420 Å and that of As-Fe is 2.370 Å.

FeAs3 in 1-c represents a quadrilateral structure with the atoms connected to each other, exhibiting point group C2v and doublet spin multiplicity. The As-As bonds connected directly has bond length 2.493Å. Similarly, the As-Fe atoms, which are directly placed at vertices, possess a bond length of 2.291Å.

The structure possessing lowest energy for FeAs4 is presented in 1-d, which is the most

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stable structure, point group C2v and singlet spin multiplicity. The structure resembles a trapezium like shape. The As-As bond length at the non-parallel sides are both 2.600 Å. The As-As bond length at top side is 2.722 Å. The Fe atom in placed in the centre of the base and the four As atoms are linked with it. The As atoms on the same side create As-Fe bonds of the length 2.308 Å and that on the opposite arm have bond lengths 2.283 Å.

The reported experimental bond length of As-As atoms is 2.414 Å-2.647 Å [52]. The computed data obtained for As-As bond length is in range with the experimentally reported value as the shortest bond length is approximately equal to the experimental value with a mere variation. The shortest bond length of As-As bond is 2.423 Å which is exhibited by FeAs2 and the longest bond length for the pair is 2.722Å which is also possessed by FeAs4.

# 3.2 Electronic attributes and DFT based characteristics

Researchers utilized electronic structure theory to computationally investigate clusters of arsenic and iron. They examined overarching features such as molecular hardness, softness, electronegativity, and electrophilicity using equations derived from density functional theory. Previous research has underscored the importance of donor and acceptor orbitals in facilitating charge transfer and bond formation. The disparity in energy levels between the highest occupied molecular orbital (HOMO) and the lowest unoccupied molecular orbital (LUMO) plays a critical role in defining electronic characteristics such as hardness and softness. A narrower HOMO-LUMO gap indicates reduced kinetic stability, with FeAs4 exhibiting the smallest gap among the analyzed clusters. However, all clusters fall within a range deemed suitable for superconducting applications.

Molecular hardness is essential in understanding cluster dynamics, representing the stability of the molecular system. FeAs2 exhibited the highest hardness, while FeAs4 showed the lowest. The hardness value correlates with the HOMO-LUMO gap, with larger gaps indicating higher hardness. Molecular softness, inversely related to the HOMO-LUMO gap, ranged from 0.301eV to 0.378eV. Electronegativity, crucial for understanding charge transfer, varied among the clusters but showed no significant deviation in magnitude. Electrophilicity index, indicating the energy reduction during orbital interactions, increased with the number of arsenic atoms in the clusters, with those with the smallest HOMO-LUMO gap exhibiting the greatest index (Table 1). Most structures, except FeAs4, displayed high dipole moments, suggesting an ionic nature of the bonds. The dipole moment correlated with structural symmetry, with FeAs2 exhibiting the highest value, corresponding to its highest HOMO-LUMO gap (Figure 2).

**Table 1:** Global descriptors based on Density Functional Theory (DFT) were employed to characterize FeAsn clusters, where n ranges from 1 to 4

Species	HOMO- LUMO Gap (in eV)	Hardness (eV)	Softness (eV)	Electronegativity (in eV)	Electrophilicity Index (in eV)	Dipole Moment (in Debye)
FeAs	3.138	1.569	0.319	4.343	6.010	3.119
FeAs <sub>2</sub>	3.318	1.659	0.301	4.525	6.172	3.784
FeAs <sub>3</sub>	2.866	1.433	0.349	4.951	8.552	2.470
FeAs <sub>4</sub>	2.645	1.322	0.378	5.116	9.897	0.062



**Figure 2:** Relation of HOMO-LUMO gap with Molecular Hardness

# 4. Conclusion

A computational study of arsenic doped iron clusters have been performed. DFT based global descriptors have been computed based on the clusters varying 1 to 4 arsenic atoms with a single Fe atom, possessing the most stable configuration. The obtained bond length of the stable state configuration for the clusters validate their reported experimental values. The computed data present with HOMO-LUMO gap, which is validated by reported values of metallic clusters. The nanoalloy clusters present with energy gap, which is suitable for superconductor applications. The minute variation of molecular hardness and softness indicates slow progression in the change in properties of the clusters. The ionic bond formed within the cluster is clearly depicted by all the clusters except FeAs4. The obtained results have opened up avenues of new research in this field.

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# 38. Determination of the quality of irrigation water by Fuzzy: Logic based system in irrigation

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#### Abstract

Recently water quality monitoring becomes an essential area of research. Since it is directly related to our daily life. The presence of minerals in water is an important factor both for human and a plant. It has been observed that, sometimes in irrigation water high amount salt is present, which is really harmful for cultivation. Since most of crops could not grow on the soils with high amount of salt. Also high concentration of some salts is really toxic to the plants. In this regard a simple two electrode based water salt monitoring system has been designed. Further, the data have been captured by Node MCU based data acquisition system and processed by using fuzzy logic model to determine the amount of salt present in water sample. It has been observed that, the developed system can determine the presence of salt amount in an unknown water sample with 90% of accuracy with the trained model. The developed system can be used for more fields testing to find salt quantities in the cultivation fields.

Keywords: Irrigation water quality, Fuzzy logic, Water quality assessment, Node-MCU

#### 1. Introduction

The environment we inhabit consists of five fundamental components: soil, water, climate, natural vegetation, and landforms. Among these, water holds a preeminent and indispensable position for human life. Its significance cannot be overstated, as it serves as a vital resource that sustains our very existence by providing us with essential life-supporting functions. Water is not only crucial for hydration and sanitation, but also for agriculture, which is the foundation of our food production. It plays a critical role in the food supply chain, serving as an indispensable ingredient for crop cultivation and livestock rearing. Furthermore, water is extensively utilized in various industrial processes, including energy production, manufacturing, and mining, making it a key component of economic activities.In addition to its direct uses, water also

plays a crucial role in regulating the Earth's climate, supporting the growth of natural vegetation, and providing habitats for a diverse range of aquatic species. It is an integral part of the natural environment and is intricately connected with the other components that comprise it. It also supports the growth of natural vegetation, which in turn contributes to carbon sequestration, air purification, and habitat creation for wildlife. Moreover, aquatic ecosystems, such as rivers, lakes, and oceans, harbor diverse and complex communities of species, making water an essential element for biodiversity conservation. Given its critical role in supporting human life, food production, economic activities, climate regulation, and biodiversity conservation, the importance of water cannot be overstated. It is a precious and finite resource that requires careful management, conservation,

and protection to ensure its availability for current and future generations [1].

Maintaining water quality balance is crucial because water is essential for all life on Earth, including humans, animals, and plants because polluted water can severely damage human health, causing illnesses and even death. Additionally, it can harm aquatic life and affect the ecological balance of entire ecosystems. Water pollution is a significant global problem that affects both developed and developing countries. Polluted water comes from many sources, including industrial and agricultural activities, improper waste disposal, and natural events like floods and storms. Chemicals, sewage, and other contaminants can also leach into water sources. So it is imperative to undertake continual evaluation and adaptation of water resource management practices at all tiers, ranging from the international to the individual level, in order to tackle the pressing issue of water pollution. This involves identifying the sources of pollution, implementing policies and regulations to reduce pollution, and promoting sustainable water use practices [2-4].

Freshwater is nothing but a world resource that really is a gift of nature and it is also too much useful for farming. Maintaining the Quality of water in cultivation fields is a challenging matter. It has been observed that, usage of chemicals in manufacturing, construction and some industries, usage of fertilizers in cultivation farms and also due to the polluted water from industries into nearby water bodies cause water quality reduction, it affects both the human and plants [5]. Water salinity tolerance of a plant is a vital issue for irrigation [6-8]. High level of salinity can resist the growth of a plant. Presently, water monitoring is an extensively research topic. Constant monitoring of water quality is an important factor for recent days [9]. So an automatic water quality monitoring is required for this purpose. In this work, a water salt monitoring system has been developed. It can determine the salt concentration in irrigation water sample.

# 2. Material and Methods

#### 2.1 Sample Preparation

In this purpose total 150 water samples are prepared by mixing several amount of salt. As well as 10 different water samples have been collected from 10 different locations, for each water sample 25 ml has been taken and 15 different concentration of brine solutions have been prepared by mixing salt. To measure very smaller value of salt weight precise weight balanced has been used.

#### 2.2 System Design

After the preparation of water samples it has tested with an electronic measurement system. It has been designed with an electrolysis chamber, a signal processing unit and a data acquisition system interfaced with computer as well as cloud server. Here, a two electrodes arrangement, a digital ammeter, an I2C converter, and a Node-MCU (ESP8266) module have been employed in this experiment, the Node-MCU (ESP8266) module has allowed us to transmit the data to a cloud server in real-time and it also collected in computer through USB port. Further the data have been processed by MATLAB 2016a software in the computer. The block diagram of the measurement system is shown in Figure 1.



Figure 1. Block diagram of the total measurement system.

#### 2.3 Data Acquisition

During this process a constant dc voltage is applied between the two electrodes, so current starts flowing through the brine solution due to presence of ions in the solution. When the power source is turned on, the current in the solution quickly reaches its maximum value. However, as time passes, the ion density in the solution starts to decrease, leading to a decrease in the amount of current flowing through the solution. It is important to note that even if the number of ions inside the solution decreases towards zero due to the electromotive force, still the conduction process never comes to an end. At the initial condition when just the power supply has been switched on current reading is zero. Since few millisecond is needed to break NaCl to Na+ and Cl<sup>-</sup> ions then current conduction starts. Then, the current readings have been captured by Node MCU module with the help of a known value resistor connected in series with power source within 3 seconds from power on. Basically, Node MCU unit captures voltage reading across the resistor and then it has internally calculated the current value. The flow chart of the measurement process has been shown in Figure 2. After capturing data it has been stored in computer through USB interfacing and data also stored in the Thing-Speak cloud server. Thing-Speak is a popular cloud server platform that caters to the needs of Internet of Things (IoT) applications. It offers a wide range of features and functionalities that enable users to collect, analyze, and visualize sensor data from connected devices in realtime. One of the key features of Thing-Speak is its ease of use in device configuration for data transmission It supports various IoT protocols such as MQTT, API, and HTTP, allowing devices to send data to the cloud server effortlessly. Thing-Speak also provide robust data visualization capabilities, allowing users to create customizable dashboards and plots to visualize sensor data in real-time. Secondly, viscosity of the brine solutions have been also measured using Ostwald Viscometer.



Figure 2. Flow chart of the measurement process.

#### 2.4 Data Processing

In this part a fuzzy inference system has been developed, where two factors of salt solutions has been considered as input parameter. Those are amount of current flowing through brine solution and viscosity of the corresponding ICCIDE\_2023

solution. During fuzzy modeling triangular membership function has been incorporated which is one of the most commonly used membership functions in fuzzy logic. Typical picture of membership functions for two input variables are shown in figure 3. Mathematically, the triangular membership function is defined as follows [12]:

$$\mu_{triangle}(x; a, b, c) = \begin{cases} 0, & x \le a \\ \frac{x-a}{b-a}, & a \le x \le b \\ \frac{c-x}{c-b}, & b \le x \le c \\ 0, & c \le x \end{cases}$$
$$= \max\left(\min\left(\frac{x-a}{b-a}, \frac{c-x}{c-b}\right), 0\right)$$



Figure 3. Membership functions of current flow and viscosity.

Further, fuzzy mumdani inference model has been formed by combining membership functions of two input parameters for different ranges in rule base. The rules are formed by applying AND /OR operations between the membership functions. A typical rule set has been shown in Figure 4:

1.1	f (Normalised_Value_of_Current is Very_low) and (Viscosity is Low) then (Amount_of_Salt is Very_low) (1)
2.1	f (Normalised_Value_of_Current is Low) and (Viscosity is Low) then (Amount_of_Salt is Low) (1)
3.1	f (Normalised_Value_of_Current is Medium) and (Viscosity is Low) then (Amount_of_Salt is Medium) (1)
4.1	f (Normalised Value of Current is High) and (Viscosity is Low) then (Amount of Salt is High) (1)
5.1	f (Normalised Value of Current is Very High) and (Viscosity is Low) then (Amount of Salt is Very High) (1)
6.1	f (Normalised Value of Current is Very low) and (Viscosity is Medium) then (Amount of Salt is Very low) (1)
7.1	f (Normalised Value of Current is Low) and (Viscosity is Medium) then (Amount of Salt is Low) (1)
8.1	f (Normalised Value of Current is Medium) and (Viscosity is Medium) then (Amount of Salt is Medium) (1)
9.1	f (Normalised Value of Current is High) and (Viscosity is Medium) then (Amount of Salt is High) (1)
10	If (Normalised Value of Current is Very High) and (Viscosity is Medium) then (Amount of Salt is Very High) (1
11	If (Normalised Value of Current is Very low) and (Viscosity is High) then (Amount of Salt is Very low) (1)
12	If (Normalised Value of Current is Low) and (Viscosity is High) then (Amount of Salt is Low) (1)
13	If (Normalised Value of Current is Medium) and (Viscosity is High) then (Amount of Salt is Medium) (1)
14	If (Normalised Value of Current is High) and (Viscosity is High) then (Amount of Salt is High) (1)
15	If (Normalised Value of Current is Very High) and (Viscosity is High) then (Amount of Salt is Very High) (1)

Figure 4. Rule set for fuzzification.

Then, to obtain single crisp output data Centroid Method of defuzzification has been used. It calculates the weighted average of the fuzzy output with respect to the universe of discourse to obtain a single crisp or numerical value as the output. The Centroid Method involves finding the center of gravity of the fuzzy output, which represents the "center" or "average" of the fuzzy set.



Figure 5. Pictorial view of Measurement system.

# 3. Results and Discussion

The initial salt measurement has been taken and mixed into the water samples. The viscosity of the brine solution has been determined using an Ostwald Viscometer. The circuit has been built by connecting Node MCU, along with a two copper electrode set up to measure the current passing through the brine solution. During data collection a single data has been captured by averaging 1000 number of ADC samples to avoid ADC data error. Before data processing both current and viscosity reading have been normalized, the fuzzy model has been formed to test unknown salt water sample. Figure of the experiment set up is shown in figure 5. The experimental data of current flow and viscosity of the salt solution and the predicted value of the fuzzy model has been presented in Table1. It has been observed that the developed system can predict salt quantity with 90% of accuracy.

Table 1.	Experimental	Data
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Normalized value of	Normalized value of	Actual salt	Predicted salt
current (mA)	viscosity (Pas)	amount (gm)	amount (gm)
0.10416	0.23052	1.3	1.28
0.25	0.71732	3.4	3.42
0.3125	0.86904	4.1	4.08
0.6458	0.8862	4.2	4.18
0.7966	1	4.7	4.72

## 4. Conclusion

This work focused to develop a sophisticated system that could effectively measure and quantify the presence of salt in irrigation water samples. By integrating sensor technology, data transmission mechanisms, and the application of fuzzy logic, the project strived to provide valuable insights for water quality assessment and decision making, ultimately contributing to the improvement of water management practices and ensuring the provision of safe and clean water resources. The successful outcome of this chapter was determined by comparing the predicted output generated by the Fuzzy logic algorithms with the actual amount of salt that was added to the water samples. Since, the predicted output closely matched the actual amount of salt, it indicated that the system has been able to accurately quantify the amount of salt in water sample before using it for cultivation.

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# 39. Utilisation of transient earth voltage in the partial discharge of power transformer

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#### Abstract

To examine any potential flaws in transformers, partial discharge characteristics are retrieved. Furthermore, an analysis and comparison of the two approaches' detection performances have been conducted in order to gain a deeper understanding of the partial discharge characteristics of transformers. It is highly beneficial to increase the accuracy of pattern identification when transient earth voltage and pulse current are used in tandem. The technique of using transient earth voltage to identify transformer partial discharge is suggested in this paper. The metrics that this approach measures are then extracted and given a quick analysis. The oily needle-plate defect, oily air gap defect, oily surface defect, and oily sphere-plate defect are the four artificial partial discharge models of transformers that have been built up. Through the use of transient earth voltage and pulse current based on phase analysis, the experiment employs the constant voltage testing method to derive the distinctive parameters from the phase spectrogram of maximum discharge capacity and discharge frequency. The phase-resolved partial discharge approach has been used to obtain partial discharge characteristic characteristics. Comparative analysis is done on the variations between each kind of discharge characteristic and the connection between the two techniques. Additionally, a pattern recognition technique based on support vector machines has been applied. The data, which were acquired using the combination of transient earth voltage and pulse current, have been examined for recognition. The full study of the two sets of data indicates a significant improvement in pattern recognition accuracy.

Keywords: transient earth voltage, pulse current, support vector machine, pattern recognition, oil-pressboard insulation.

#### 1. Introduction

Power transformer ageing and insulation damage can result from partial discharge. There are significant theoretical and practical implications for the research of transformer partial discharge. Owing to the intricacy of the transformer's construction, a multitude of partial discharge scenarios are highly probable. Regarding various partial discharge forms, the amount and detrimental impacts of each form of discharge also vary. Therefore, pattern recognition technology is required in transformers. The ultrasonic and pulse current methods are commonly employed for detecting partial discharges in current systems. However, there are glaring errors in the application. The structure of power transformers is intricate, and there are persistent issues with pattern recognition accuracy [1].

The pulse current method's response frequency is typically less than 10MHz. It is unable to react completely to the partial discharge characteristics. The transient earth voltage detection method is less frequently used to identify oil-paper insulation applications and more frequently used to detect partial discharge in high voltage switchgear. This study demonstrates the method's ability to detect power transformer partial discharge. The transient earth voltage method's detection frequency ranges from 3 MHz to 60 MHz, enhancing the characteristics of partial discharge signals. This work describes the use of transient earth voltage and pulse current methods to detect partial discharge of power transformers. Analysis is done on four traditional power transformer partial discharge models. Additionally, pattern recognition uses the support vector machine technique to demonstrate the superiority of the combined approach [2-3].

## 2. Experimental System and Method

#### 2.1 The Principles of Transient Earth Voltage

The power transformer experiences partial discharge, which releases electromagnetic waves through the oil discharge valve, transformer casing seams, and other components. And it fills the atmosphere. A partial discharge of a high-frequency signal produces electromagnetic waves, which propagate across the transformer box's exterior. Thus, there is a pulse signal to ground. Capacitive sensors detect transient ground voltage. Installing sensors is simple because they may be connected straight to the transformer wall.

#### 2.2 Experimental Circuit and Its Models



Figure 1: Diagram of experimental system

AC denotes a 0~50kV tunable no-discharge AC source in Figure 1. The protective resistor, or Ri, is 10k<sup>^</sup>. The coupling capacitance, or Cj, is 830 pF. The impedance for capacitive detection is Z. The test item is CX.

In Figure 2, a transient earth voltage sensor is displayed. It has a 3 to 60 MHz bandwidth. It is possible to affix the sensor to the metal casing.

Figure 3 displays the electrodes used in the experiment. The needle electrode's radius of curvature (p) is 100 pm. The copper electrode's surface roughness, Ra, is 3.2pm. The spherical electrode has a 20mm diameter. The column electrode measures 25 mm in height and 25



Figure 2: Sensor of transient earth voltage

mm in diameter ^2. The insulating board is 120 mm long in the needle-plate defect, sphere-plate defect, and air gap defect types. The length in the surface defect model is 70 mm. Each sheet of insulating board has a thickness of 1 mm. After drying, the insulating board is submerged in oil for 48 hours. The gap diameter in the air gap defect model is 40 mm [4].



Figure 3: Models of experimental electrode

#### 2.3 Experimental Method

The plate electrode is grounded and set in place. Next, ground the transformer model's metal shell and fasten the TEV sensor to it [5]. Raise the AC voltage gradually until the partial discharge happens. At the end, the AC constant voltage is between 1.2 and 1.5 times higher than the initial voltage. In this study, the needle-plate defect, sphere-plate defect, and surface defect models have a final selected voltage of 15 kV. The voltage in the air gap fault model is 5 kV. The oscilloscope's sampling frequency is 50 MHz. The measurement is thirty AC cycles per hour. Each model stores 40 groups of data, with 10 cycles being considered a group.

# 3. Characteristic Pattern of Partial Discharge Signal and Calculation of Statistical Parameter

# 3.1 Characteristic Pattern of Partial Discharge Signal

In the same paradigm, the PRPD characteristic pattern data are periodic. It is possible to tally the partial discharge data over multiple time periods and determine the PRPD characteristic pattern. The PRPD characteristic pattern varies for many models. It is possible to distinguish between several models as a result of this difference [6].

The techniques of transient earth voltage and pulse current are applied in this paper. The amplitude distribution of the number of discharges  $H_{u}(q)$ , the phase distribution of the number of discharges Hn(f), the phase distribution of the average discharge amplitude Hqmeafy, and the maximum discharge amplitude Hqmax(f) are derived. Every pattern has partial discharge information. Regarding the many models. The pulse current approach, a conventional technique for detecting partial discharge, yielded the representative PRPD pattern. The PRPD pattern, as determined by the pulse current approach in the sphere-plate defect model, is depicted in Figure 4 [7]. The transient earth voltage approach has a bandwidth of 3 to 60 MHz. Compared to the pulse current method, this method is more able to capture the features of partial discharge. The



Figure 3: a) Hqmax( $\phi$ )



**Figure 3:** b) Hqmean( $\phi$ )



**Figure 3:** d) Hn(q)

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pulse current measurement yields a distinct PRPD pattern than the transient earth voltage measurement. In the same model of sphere-plate defect at the same voltage, Figure 5 displays the PRPD pattern as detected by transient earth voltage.

The identical experimental setup is used to measure the data for the pattern mentioned above. It is evident that the two methods' measurements of the phases of partial discharge signals centre at 90° and 270°. Bimodal waveforms are also seen. The fact that the data acquired using the two approaches differs in some way is meaningless. The stray capacitance has less of an impact on the pulse current technique. Therefore, this method has less interference. Compared to pulse current measurements, transient earth voltage measurements yield more complete data. Interference has the ability to easily affect it. Thus, a higher threshold is required to delete it.



Figure 4: Pattern of partial discharge measured by transient earth voltage.



Figure 5: Pattern of partial discharge measured by pulse current.

#### 3.2 Calculation of Statistical Parameter

The identical experimental setup is used to measure the data for the pattern mentioned above. It is evident that the two methods' measurements of the phases of partial discharge signals centre at 90° and 270°. Bimodal waveforms are also seen. The fact that the data acquired using the two approaches differs in some way is meaningless. The stray capacitance has less of an impact on the pulse current technique. Therefore, this method has less interference. Compared to pulse current measurements, transient earth voltage measurements yield more complete data. Interference has the ability to easily affect it. Thus, a higher threshold is required to delete it [8-9].

# 4. Characteristic Pattern of Partial Discharge Signal and Calculation of Statistical Parameter

#### 4.1 Support Vector Machine

Based on the statistical learning theory, the support vector machine method uses the VC-dimensional theory. Additionally, the structural minimum risk principle forms the basis of this approach. Based on the small sample size, model complexity, and learning capacity, the algorithm finds the optimal answer. To divide the two training samples, the algorithm creates the best classification surface in a high dimension using either the projection or the original space. The support vector machine principle is as follows in the linear separable case [10].

#### 4.2 Pattern Recognition of Statistical Parametric Factor

For every experimental model, fifteen sets of experimental data were utilised as learning samples. For the purpose of detection, twenty-five data sets are used. Each of the four experimental models tests a total of one hundred pieces of data. The data obtained by the pulse current method, the transient earth voltage method, and the combined data obtained by the two methods are all subjected to pattern recognition. Tables 1, 2, and 3 display the results, with m denoting the number of samples to be tested and n denoting the number of samples that must be accurate [15].

Table 1: Test result of pulse current

PD type	m	n	Accuracy (%)
Needle Plate	25	17	68
Spare Plate	25	23	92
Air gap	25	18	72
Surface	25	16	64

Table 2: Test result of transient earth voltage

PD type	m	n	Accuracy (%)
Needle Plate	25	17	68
Spare Plate	25	20	80
Air gap	25	19	76
Surface	25	22	88

Table 3: Test result of Integrated Method

PD type	m	n	Accuracy (%)
Needle Plate	25	20	80
Spare Plate	25	23	92
Air gap	25	22	88
Surface	25	21	84

## 5. Conclusion

25# transformer oil is used to fill the experimental model. The four models of needle-plate, sphere-plate, air gap, and surface imperfection are used to conduct the experiment. Transient earth voltage and pulse current measurements are used to compare and analyse the results from the two approaches. Verified are the benefits of the integrated technique and the viability of transient earth voltage. The following are the primary conclusions.:

1. For the discharge signals of four distinct models, the PRPD pattern is established.

Four types of discharge pattern skewness and kurtosis are computed.

- 2. The PRPD pattern is compared using the transient earth voltage and pulse current approach. It is evident that the two approaches share similar qualities. The transient earth voltage method's detection frequency ranges from 3MHz to 60MHz. Furthermore, the pulse current method's detection frequency is lower than 10MHz. Compared to pulse current data, transient earth voltage data is more complete. The transient earth voltage probes, however, are more vulnerable to spatial interference. The precision of transient earth voltage is slightly higher than that of pulse current, as can be seen using the support vector machine approach. The properties of partial discharge are more clearly reflected in the data obtained from transient earth voltage measurements.
- 3. The data produced by the two ways are completely calculated based on the analysis presented above. It is discovered that the integrated approach can raise the partial discharge pattern detection accuracy.

while concrete with 10% RHA displays the lowest strength. On average, 10% of cement was replaced. Specimens with lower water-to-cement ratios show less variance in flexural strength. The average reduction in flexural strength was 25%, with a 15% substitution of cement. Therefore, when taking into account flexural strength, it is recommended to employ a lower water-tocement ratio (10% replacement of cement by RHA). These results demonstrate that there is very little variation in the strength of the RHAreplaced concrete in the first 14 days.

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# 40. Performance analysis of a three-phase cascaded H-bridge multilevel inverter

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#### Abstract

Earlier research has highlighted the shortcomings of traditional inverters, particularly when it comes to high voltage and high power applications. Because of their higher power ratings and better harmonic profile, multilevel inverters have grown in popularity recently for high power applications. The literature include reports on studies on topology, control strategies, and multilayer inverter applications. Nevertheless, no hard data exists that genuinely analyses or assesses a three-phase multilevel inverter's performance. This work provides an investigation of the performance of a multi-carrier sinusoidal pulse width modulation (MSPWM) control technique-based 5-level cascaded H-bridge multilevel inverter (CHMI). Based on the findings of a simulation study done using MATLAB/ Simulink to explore how the CHMI operates, performance analyses are made. Several unique characteristics of the three phase 5 level CHMI using the MSPWM control scheme have been identified based on the findings of the simulation research and the analysis carried out. Of particular note is the phase disposition (PD) type of the carrier disposition (CD) method from the perspective of line voltage.

Keywords: Multilevel inverter, cascaded, three-phase, high power applications

## 1. Introduction

Many power electronics applications that require control over the frequency and magnitude of an AC output employ switch-mode inverters. Inverters are practically utilised in three-phase and single-phase AC systems. The most basic topology for an inverter that generates a two-level square-wave output waveform is a half-bridge inverter. In this configuration, a center-tapped voltage source supply is required. Conversely, two- and three-level output waveforms are synthesised using the full-bridge architecture. These traditional two- and three-level inverters can't handle high voltage and high power conversion without significant limits, though. These converters are linked in series with transformers for increased output voltage capacity and decreased harmonic distortion; however, transformers are the primary cause of issues like bulkiness, high loss, and high cost to the entire AC system. Aside from that, switching losses and device rating restrictions are the primary causes of the high frequency operating difficulties of traditional inverters. Concerns about the intricate structure are also raised by the dynamic voltage balance circuit [1].

Because of this, multilevel inverters—which have their own circuit architecture and can produce high voltage and lower harmonics—are starting to emerge as a new breed of power converter choice for high power applications [1]. Numerous high- to medium-power industrial applications, including motor systems, static VAR compensators, and AC power supplies, use multilevel inverters. A staircase output waveform can be created by combining many levels of DC voltages to create the AC output terminal voltage. This reduces the voltage stress on the switches and permits a larger output voltage. In high power applications, multilevel inverters have emerged as a viable and efficient way to lower switching losses [2]. Moreover, the synthesised output adds steps in proportion to the number of voltage levels on the DC side, resulting in an output that approaches a sinusoidal wave with the least amount of harmonic distortion. As a result, less output filter is needed [3].

Multilevel inverter circuits have been around for more than 25 years, according to the results of a patent search [4]. The neutral point clamped inverter topology was first introduced by Nabe et al., marking the beginning of the evolution of multilevel inverters. When this design is applied, the resulting three-level output voltage waveform performs significantly better spectrally than the standard inverter's. Bhagwat and Stefanovic then used various levels to improve the spectral structure of the output waveforms. These multilayer inverters not only enhance waveform quality but also significantly lessen voltage stress on the components. Generally speaking, these inverters are referred to as diodeclamped multilevel inverters (DCMI). The clamping diodes' necessary voltage blocking capacity changes according to the levels in this kind of multilayer inverter. Meynard's flying capacitor multilevel inverter is an alternative to the DCMI. In this inverter topology, clamping capacitors are used to limit the voltage across an open switch rather than clamping diodes.

The cascaded H-bridge multilevel inverter (CHMI) is a significantly simpler multilevel inverter topology with less power device requirements than the ones previously discussed. However, because it has a 406 isolated DC power supply requirement for every stage, it is appealing for use in applications involving alternative or renewable energy sources that can provide DC output that is readily available. The use of single-phase and three-phase CHMI in driving and static applications has been documented in a number of recent publications.

Thus, based on the findings of a simulation study, this work discusses some of the characteristics of a three-phase CHMI that are recognised in terms of several performance criteria. The three-phase CHMI circuit architecture and the various multicarrier sinusoidal pulse width modulation (MSPWM) methods are briefly explained in the section that follows. The simulation study's findings are then discussed and examined, and the paper's conclusion highlights the key components of the three-phase CHMI.

# 2. Three-phase CHMI Circuit Configuration

The output of three identical single-phase CHMI structures can be coupled in a delta or wye configuration for a three-phase system. The schematic diagram of a wye-connected m-level CHMI with independent DC sources is shown in Figure 1.

Each phase of a three-phase, five-level CHMI requires two H-bridge cells with eight switches. For this circuit arrangement, a total of six Hbridge cells including 24 power switches are needed. This implies that in order to feed the switches with gating signals, twelve pairs must be generated. There are two high-frequency switches and two low-frequency switches for every H-bridge cell because the switches operates at the carrier frequency and the other pair operates at the reference frequency.

The voltage of phase A, or VAN, is represented by Figure 1 and is the total of Val, Va2,... Va (S-1) and VaS. Phases B and C are subject to the same concept.

Next, two phase voltages are used to express the line voltages. For instance, VAB, the potential between phases A and B, can be calculated using the following formula:

$$V_{AB} = V_{AN} - V_{BN} \tag{1}$$

Where, The line voltage is VAB. The voltage of phase A relative to neutral point N is known as VAN. The voltage of phase B in relation to neutral point N is known as VBN.



Figure 1: A general three-phase wye configuration CHMI

# 3. Multi-Carrier Sinusoidal Pulse Width Modulation (MSPWM) Technique

#### 3.1 Basic Principle

Using several triangular carrier signals with a single modulation signal per phase is the foundation of multiphase phase modulation. (m-1) triangular carriers with the same frequency (fc) and amplitude (Ac) are arranged in continuous bands for an m-level inverter. In the centre of the carrier set is where the zero reference is located. A sinusoidal signal of amplitude Am and frequency fm makes up the modulation signal. Every carrier signal is compared to the reference modulation signal at every time. If the reference signal is higher than the triangular carrier allotted to that level, each comparison turns the device on.

The gadget shuts off else [1].

Four carrier waveforms, each spaced 1200 phases apart, are required for a three-phase, five-level CHMI. These waveforms must be compared to the reference waveforms at each time [5]. The MSPWM method for a three-phase, five-level CHMI is displayed in Figure 2.



Figure 2: MSPWM technique for a 3-phase 5-level CHMI

The MSPWM approach [5] requires consideration of three primary parameters: the amplitude modulation index (ma), which is defined as,

$$m_a = A_m / N A_c$$
 (2)

where, 
$$N = (m - 1)/2$$
 (3)

m is the number of levels of the multilevel inverter (odd),  $A_m$  is the amplitude of the modulating signal,  $A_c$  is the peak to peak value of the carrier (triangular) signal

The frequency modulation index

$$m_f = f_c/f_m$$

 $f_c$  is the frequency of the carrier signal and  $f_m$  is the frequency of the modulating signal.

The displacement angle between the modulating signal and the initial positive triangle carrier signals is the third parameter. A zero displacement angle is used in this work.

#### 3.2 Category and Disposition Methods

Generally speaking, there are three types of MSPWM techniques: hybrid (H), phase-shifted (PS), and carrier-dispersion (CD) [7]. The PS approach involves phase shifting multiple carriers in accordance with the reference waveform, whereas the CD method samples the reference waveform through a series of carrier waveforms displaced by consecutive increments of the reference waveform amplitude. The H method, on the other hand, combines these two approaches. The gating signals for the CHMI switches will be obtained in this work using the CD approach.

Phase Disposition (PD), Phase Opposition Disposition (POD), and Alternative Phase Opposition Disposition (APOD) are the three alternate carrier disposition methods that can be used with the CD method [6].

According to Figure 2, every carrier signal is in phase with the PD scheme. The carrier signals above the zero reference value are in phase with the POD scheme. Although the carrier waveforms below zero are 1800 phase displaced from those above zero, they are still in phase. On the other hand, each carrier signal in the APOD scheme must be phase-shifted 1800 alternatingly from its neighbouring carrier [6]. While all three of the alternative carrier disposition strategies were used in this work to adjust the three-phase CHMI, the focus of this paper is mostly on the outcomes of the PD scheme in contrast to the other schemes and the traditional three-phase bridge inverter that uses the SPWM methodology.

## 4. Results and Analysis

With MATLAB/Simulink, the three-phase, five-level MSMI is simulated. Assumptions for the simulation study include an inverter load

(4)
that is pure resistive, a DC voltage input of E = 400V to each module, and a fundamental frequency of fm = 50 Hz for the output voltage. The three-phase CHMI's line voltage is analysed and compared using the MSPWM approach (PD scheme), with respect to the output voltage waveforms, output voltage harmonic spectrums, fundamental voltage, and total harmonic distortion (THD).

# 4.1 Effect of Odd and Even mf on the Line Voltage Waveforms

The line voltage waveforms for a three-phase, five-level CHMI using the PD scheme with values of ma = 0.8 and mf = 39 and mf = 60, respectively, are displayed in Figures 3 and 4.

Regardless of whether mf is odd or even, it is evident from the figures that the line voltage waveforms for the PD scheme are not symmetrical. More switchings will show up in the waveforms when mf rises while ma stays unchanged. This is compliant with (2). Due to the constant fundamental frequency, fm, an increase in mf likewise results in an increase in fc. Consequently, there will be an increased number of intersections or comparisons between the carrier and modulating signals.



**Figure 3:** Line voltage waveform for a three-phase CHMI with PD scheme (mf= 39, ma= 0.8).



**Figure 4:** Line voltage waveform for a three-phase CHMI with PD scheme (mf= 60, ma= 0.8).

# 4.2 Relationship between ma and Number of Levels in the Line Voltage

The line voltage waveforms for the three-phase, five-level CHMI using the PD scheme, with mf fixed at 39 and changing ma, are displayed in Figures 5 to 8. The maximum number of levels that the line voltage can synthesise is nine, as shown in Figure 5. The highest number of levels in the line voltage waveform that may be achieved is often 4s + 1. This is because s is the number of DC sources per phase, and in the case of a 5-level CHMI, s = 2.

The outcomes of the simulation study are compiled in Table 1. The three-phase CHMI can accomplish up to nine levels, in contrast to a single-phase 5-level CHMI with PD scheme, which can only achieve two separate levels of 3 and 5 in its output voltage waveform. The synthesised line voltage waveforms are predicted to significantly reduce harmonic distortion and resemble a sinusoidal waveform at greater levels of three-phase CHMI. Furthermore, a three-phase CHMI's ma can be set significantly lower than that of a single-phase CHMI (ma < 0.6) before it begins to operate like a typical three-level inverter.



**Figure 5:** Line voltage waveform for a three-phase CHMI with PD scheme (mf= 39, ma= 0-9)



**Figure 6:** Line voltage waveform for a three-phase CHMI with PD scheme (mf= 39, ma= 0.6)



**Figure 7:** Line voltage waveform for a three-phase CHMI with PD scheme (mf= 39, ma= 0.3)



**Figure 8:** Line voltage waveform for a three-phase CHMI with PD scheme (mf= 39, ma= 0.2)

**Table 1.** Number of levels achieved by a three-<br/>phase CHMI with PD scheme (mf= 39)

Modulation Index	Number of Levels
> = 0.9	9
0.6 - 0.8	7
0.3 - 0.5	5
< 0.3	3

#### 4.3 Harmonics Analysis on the Line Voltage

The harmonic spectrums of the line voltages of a five-level, three-phase CHMI using the PD scheme are displayed in Figures 9 and 10. These figures show that for odd mf, only odd harmonics are discovered, whereas for even mf, both odd and even harmonics are found. It is discovered that this feature is comparable to a single-phase CHMI. Because the inverter phase legs cancel each other out, there is no highly significant harmonic shown in the harmonic spectrums of Figures 9 or 10 [8]. Rather, it is discovered that only the first significant harmonic's occurrence (29 for mf = 39 and 50 for mf = 60) is identical to that of a single-phase 5-level CHMI.

The line voltage harmonic spectrums for a three-phase, five-level CHMI using the PD scheme with odd and triplen mf (63) and odd mf (65) respectively are displayed in Figures 11 and



Figure 9: Line voltage harmonic spectrum for a threephase CHMI with PD scheme (mf= 39, ma= 0.8)



**Figure 10:** Line voltage harmonic spectrum for a threephase CHMI with PD scheme (mf= 60, ma = 0.8)

12. The figures show a similar harmonic pattern, suggesting that adding mf alone would be more beneficial than retaining an odd and triplen mf. This is in contrast to the traditional three-phase SPWM inverter, wherein if mf is selected to be odd and triplen, then all of the triplen harmonics are absent from the line voltage [9].



**Figure 11:** Line voltage harmonic spectrum for a threephase CHMI with PD scheme (mf= 63, ma = 0.8)



**Figure 12:** Line voltage harmonic spectrum for a threephase CHMI with PD scheme (mf= 65, ma = 0.8)

#### 5. Conclusions

Based on the simulation investigation, a number of unique characteristics of the three-phase 5-level CHMI with PD scheme from the line voltage perspective may be found. Compared to the phase voltage, the line voltage may synthesise more levels, giving the appearance of a more attractive sinusoidal waveform. In addition, the line voltage reduces the requirement for an output filter by producing improved spectral performance. In addition, compared to single-phase CHMIs, three-phase CHMIs can generate line voltages with substantially reduced THD but greater fundamental.

The investigation also reveals that applying an odd and triplen mf to the 5-level CHMI does not specifically improve its harmonic performance, in contrast to the traditional three-phase SPWM inverter. The primary carrier component between phase legs cancels when the line voltages are formed, giving the PD scheme an advantage in three-phase applications. The PD modulation approach introduces the lowest line voltage THD at high modulation index.

In summary, the findings indicated that the three-phase CHMI is best suited for operation at a high ma of no more than 1 as well as a high mf. A greater basic output voltage, more levels, and less noticeable harmonics are all promised by high ma. Conversely, a higher mf guarantees a larger separation between the fundamental component and the first significant harmonic, which facilitates the filtering process.

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# 41. Domestic reforms of electricity market

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#### Abstract

At the United Nations General Assembly in September 2020, China pledged to reach "peak carbon dioxide emissions" before 2030 and "carbon neutrality" before 2060. The power industry's crucial role in supporting "peak carbon dioxide emissions and carbon neutrality" was then highlighted by China at the Climate Ambition Summit. The crucial questions, including what type of electric market to construct and what type of primary energy would be chosen to construct the power system, were put forth. The "source, network, load, and storage" links will undergo major adjustments for the new power system. The electrical market reform, however, also cannot be disregarded. One of the crucial studies that needs to be investigated at the moment is how to identify the type of electricity sales company and how to design an appropriate electricity sales strategy. In order to analyse the primary group of electricity sales enterprises affected by China's new power system reform, we first assessed the state of domestic and international electricity market change. Finally, a proposal for reforming the electrical market is made.

Keywords: electricity market; market reform; price packages; main body of electricity sales company; demand response

# 1. Introduction

Investigating the impact of the electricity market reform on electricity sales is vital to achieve the low-carbon transformation of power systems and promote the widespread development of renewable energy power generation. Researchers from home and abroad have studied the electrical market reform, but there is still a disconnect between the development objectives and the reality of electricity sales.

In this study, we first categorised the primary group of energy sales enterprises in China's new power system reform. The current state of the reform of the foreign electricity market is then examined. Finally, we examine the issues with the current electricity sales strategy in light of China's electrical market reform and offer some suggestions. The remainder of this essay is structured as follows. The primary group of energy sale firms under China's new power system reform is described in Section II. The current state of the reform of the international electricity market is introduced in Section III. The current state of China's electrical market reform is examined in Section IV. Then, in Section V, suggestions are made.

# 2. Principal Organization of China's New Power System Reformation

The Reform Measures of the Three Major Electricity Sales Subjects, Access Conditions, and Supervision Methods of Electricity Sales Companies After the Reform are highlighted in the Implementation Opinions on Promoting the Reform of Electricity Sales Side. They can choose from a variety of power purchase and sale schemes because each of them has unique advantages, weaknesses, and characteristics. This is important for the reform of the electricity sales side. The electricity sales companies are divided into three main electricity sales entities, namely, the electricity sales companies of power generation enterprises, the electricity sales companies of power grid enterprises, and independent electricity sales companies, based on the two criteria of whether to provide guaranteed power supply service and whether it has the right to operate the distribution network. Table 1 lists the benefits, drawbacks, and traits of the three electricity sales firms.

Company Name	Advantage	Disadvantage
Electricity sales companies of power generation	<ol> <li>Strong risk-resistance skills</li> <li>Possess the authority to oversee the distribution network and the means of generating power</li> <li>Across the nation</li> </ol>	<ol> <li>consumers with limited electricity needs</li> <li>No service for a reliable power supply is offered</li> </ol>
Electricity sales companies of power grid enterprises	<ol> <li>Strong risk-resistance skills</li> <li>A wide variety of power users</li> <li>It can offer services with value added.</li> <li>Wide sales platform and extensive expertise in the sale of power</li> </ol>	<ol> <li>A single sales approach</li> <li>Decision-making that is rigid and ineffective</li> <li>No ability to generate electricity</li> </ol>
Independent electricity sales companies	<ol> <li>Different electricity sales strategies</li> <li>Decision-making flexibility</li> <li>Broad sales channels and effective sales skills</li> </ol>	<ol> <li>Low risk tolerance and high risk exposure</li> <li>Lack of capacity for power production and delivery</li> </ol>

Table 1 lists the benefits, drawbacks, and traits of the three electricity sales firms.

# 2.1 Power generation companies' electricity sales firms

In recent years, China's wind turbines and photovoltaics have experienced spectacular growth thanks to the progressive strengthening of the electricity system and the encouragement of regulations. The structure of the power supply and the condition of supply and demand in these regions have changed due to the rapid development of renewable energy power generation, creating new issues for the market development of regions with a high concentration of new energy sources. The installed energy capacity is expanding quickly in regions with a large supply of renewable energy sources, outpacing the rise in local electricity consumption by a wide margin. As a result, there is a plentiful supply of electricity and there is a persistent surplus. According to China's economic and energy characteristics, regions with low levels of economic growth have abundant energy.

# 2.2 Corporations that sell electricity to power grid firms

In the market competition, the energy sales firms of the Chinese power grid corporations,

such as State Grid, China Southern Power Grid, and their affiliated electricity sales companies, hold a considerable monopoly position. The power grid firms' energy sales organisations deal with a diversity of consumers, market their products in numerous locations, and possess a high risk-resistance capacity. The obligation of ensuring the minimal level of power supply service is also taken on by the energy sales firms of power grid corporations, which boosts their sales. The electricity sales companies of power grid enterprises, however, have a single sales strategy and typically sell electricity in accordance with the regulatory authorities, much like the electricity sales companies of power producing organisations. Their decision-making is therefore rigid and ineffective. It is also essential to buy electric energy from electricity sales companies of power generation enterprises and then sell them to others, which raises their sales costs. In addition, the electricity sales companies of power grid firms do not have any generation rights.

## 2.3 Firms that sell power on their own

Enterprises like aggregators or integrated energy systems are examples of independent

electricity sales enterprises. These businesses are supported by social capital and must adhere to national admission standards. There are numerous varieties of independent power sales businesses, each with a particular customer base and scope of electricity sales. Additionally, independent electricity sales organisations lack the powers to operate distribution networks and generate power. When other users need to buy power, they buy it from other electricity sales firms or users, store it, and then resell it to them for the difference in price. Independent power sales businesses therefore have a very high operational risk, and they must entice customers by offering premium electricity and value-added services, sophisticated electricity sales methods, and a range of social benefits. The aforementioned traits so define the company's potential for selling electricity.

# 3. Reform of the Foreign Electricity Market Currently

Many nations started the upswing of power system reform at the turn of the 20th century. Britain, the first nation to begin power system reform, accelerated the growth of its economy by establishing a new way for the electricity market to operate. Following this, the United States, Japan, Northern Europe, and other nations and regions began the process of reforming the power market. There are numerous methods for the selling and purchase of energy now that more than 20 years have passed and the electrical market mechanism has essentially been upgraded.

#### 3.1 Current situation of Electricity Market Reform in Britain

Britain has undergone four power system modifications since 1989. Electricity sales face the most vigorous competition, and the pricing mechanisms for power generation, transmission, distribution, and sales are all transparent. The Office of the Gas and Electricity Markets (Ofgem), in particular, determines the maximum revenue, charging method, supply guarantee, and penalty method of retail companies for British electricity companies; the government only keeps track of the level of competition in the electricity market.

Because of the government's leadership and regulatory role, different businesses in the UK use various pricing strategies. For instance, Scottish Power, the second-biggest electrical business in Spain, uses standard pricing and time-of-use pricing, whereas British Gas, the largest energy retailer in the UK, uses single rate pricing and double rate pricing. Users who have installed time-of-use ammeters can select timeof-use price packages like economy 7, off-peak and white metre 6, among others, at the same time. Additionally, the pricing policies of the same firm will vary depending on the region, and the electricity sales businesses of the same company will still compete for the electricity supplied by the power producing companies. Additionally, in order to promote the growth of renewable energy and low-carbon power generation, the British government proposed the green energy on-grid tariff (feed-in tariff) in

2010. Additionally, in order to encourage the production and use of green energy, power providers are mandated to acquire renewable energy created, such as solar electricity generation, even though the purchase price is significantly higher than the grid price.

## 3.2 United States is Reforming its Power Market

The introduction of a competition mechanism is the main goal of the American energy market reform on the sales side. Because of the peculiar nature of the American political system, each state in the union freely develops its own regulatory framework to suit its own circumstances. As a result, several states still do not allow for the sale of electricity, and therefore continue to practise monopoly power distribution. Consumers are also unable to select their own power supply companies.

Use Texas as an illustration. Texas is the only state in the union to begin reform from the perspective of electricity sales, and its revision of the electricity market is comparatively flawless. There are hundreds of different electricity sales packages offered by its major transmission and distribution companies. For instance, in the United States, "www.powertochoose.org" allows you to select several electricity sales packages independently, and its efficiency is considerably higher than that of offline electricity sales. To use this website, enter the region's postcode. Some businesses in Texas have also introduced the "one cent" package, and the components that use more than 1000 kilowatts of electricity are taxed at a rate of one cent per kilowatt-hour and set a minimum electricity consumption, which draws many customers to choose their electricity sales companies.

One benefit of American power sales is that they use the internet, big data, and other cutting-edge technology to conduct precise marketing without affecting the electricity market price, which is something China can learn from the United States. For instance, by working with the smart home company Nest, the US electricity sales company can lower users' electricity consumption rates and lower the cost of intelligent air conditioners; by working with the Opower company, users can access detailed electricity consumption data and receive comparison reports with their neighbours' and the previous month's electricity consumption. Users can buy and save electricity in accordance with their circumstances in this way.

#### 3.3 Nordic Countries' Current State of Power Market Reform

The first international power market to open up transnational electricity trading is the Nordic electricity market. Its structure entails the division of a competitive market from a non-competitive market as well as the separation of the retail market from the wholesale market. Electricity charges for Nordic citizens are collected independently from transmission and consumption charges. Residents have the option of buying electricity from local businesses, businesses that sell electricity in neighbouring areas, or even "cross-border" businesses that sell electricity. There are several price contracts, and its retail market is comparable to that in Britain and the US. The users must be notified two months in advance if the electricity sales organisation has to change the electricity price. The contract with the electricity sales firm must be terminated by the user one week in advance if they choose to switch electricity suppliers.

The administration of its electrical sales organisations, the separation of transmission and distribution from electricity costs, and other market procedures are all things that China can learn from the Nordic cross-border electricity market. In the future, China may build distribution networks and substations along its border in order to sell power and energy to nations who are developing nearby or that are lagging behind China.

# 4. The State Of China's Electrical Market Reform

A fresh phase of electricity market reform kicked off in 2015 with the publication of the No. 9 paper (Some Opinions on Further Deepening the Reform of Electric Power System). Electricity sales businesses, which make up a significant portion of the electricity sales sector, have a lot of opportunity for improvement. The traditional monopolistic power supply strategy is no longer appropriate for the current situation in China, so we need some electricity sales strategies that can apply to the sales companies after reform. At the same time, the concept of "energy internet" is gaining more and more attention, and clean energy sources like photovoltaic electricity generation and wind electricity generation are developing.

The purchase and sale of electricity by spot market, bilateral contract, and integrated electricity sales company are taken into consideration by Kazem Zare and A. J. Conejo. Based on the spot market and bilateral contract, the value of risk skewness is taken into consideration, and the electricity sales strategy of a dynamic purchasing portfolio is designed in . A two-tier model of power suppliers and electricity aggregators is constructed in, and its impact on power suppliers' decision-making is investigated in order to maximise the profitability of electricity aggregators; The majority of the aforementioned material takes the profitability of electricity sales corporations into account, but rarely takes consumer requirements into account. As a result, it is challenging to draw in more customers after the electrical market change.

In his discussion of demand response's use in the domestic electricity retail market, Ming Zeng examines a number of successful cases and outlines the benefits and potential uses of a dynamic electricity price; explore the impact of time-of-use pricing on energy sales companies' risk aversion and demand responsiveness; Nadali Mahmoudi investigates several demand response models based on return and price, talks about the stochastic energy procurement challenge faced by retailers, and offers a number of long-term and immediate demand response protocols; Zhisheng Zhang investigates the demand response model based on logistic function and analyses the various outcomes of various influencing elements under various power prices based on the theory of consumer psychology. Despite the fact that the aforementioned literature examines the effect of consumers on the profits of electricity sales businesses, the most of them are based on just one type of energy and do not take into account the potential applications of clean energy following the reform of the electricity market. We should take into account the power sales strategy of merging clean energy and users under the development trend of "the self-use of clean energy" in the future.

The paper applies distributed generation and adjustable load to the best possible dispatch of electricity sales firms. An ideal dispatching model is built with the aim of maximising energy sales profits while taking into account the desire for operation security and economy of electricity sales firms. However, the multi-time scale electricity buy and sale strategy is not taken into account. Sayyad Nojavan explores different electricity price contracts and pricing strategies while also researching distributed power supply, renewable energy, energy storage, and alternative electricity buying methods. The real-time price strategy of a microgrid is investigated in using Stackelberg game theory. The transaction between the electricity purchasing users and the electricity sales companies is regarded as a two-person static game, and the electricity price is determined by Bayesian Nash equilibrium based on the auction model quoted by both parties. Yungi put forth a concept for operational planning for the electricity and carbon emissions trading market that is coupled.

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# 42. Effects of wind energy on the Finnish electrical market

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#### Abstract

Along with the Nordic nations, Finland was a pioneer in the deregulation of its electrical markets. With the entry of numerous small wind power firms into the market starting in 2011, Finland has seen a notable increase in wind power, and the trend is still going strong. The deregulated market's competition and possibilities for market power are impacted by wind power's rapid rise. As a result, this contribution examines how wind power affects market power potential on the Finnish energy market. The Herfindahl-Hirschman-index and the Lerner index are used to examine the market power potential. Between 2005 and 2018, the HHI demonstrates an increasingly decentralised market with greater integration of wind power. The impact of wind power can be seen as a mild trend towards decreased market power potential with increased wind power production, despite the Lerner index's high reliance on the spot price.

Keywords: Electricity markets, Wind Power, Herfindahl Hirschman-index, Lerner index, market competition

# 1. Introduction

With a deregulation process that began in the 1990s, Finland has been a pioneer in the deregulation and liberalisation of its electrical markets, along with the Nordic countries. It has been proposed that liberalised power markets would increase economic efficiency. greater service quality, lower electricity costs, and better innovation in the industry follow the greater efficiency. However, one market participant's power to solely control market pricing in the absence of competition poses a risk to free competition. A market actor is said to be using market power if they can economically change prices from levels that are competitive. Another development on the energy markets is the growth of renewable energy, in Finland and the Nordics especially wind power. Wind power has since the 1990s been the fastest growing form of electricity production globally. The characteristics of wind

power such as its distributed availability, varying production and small-scale projects makes it a special actor on the electricity market. The rapid growth of wind power into an increasingly significant player on the market, can have affected the competition situation on the market. This growth in wind power was achieved by Feed-in Premium with a guarantee price of 83 €/MWh, but currently new wind power is being built also without subsidies. This growth in wind power was achieved by Feed-in Premium with a guarantee price of 83 €/MWh, but in 2019 production covering 8% of the demand increased the importance of studying the effects of wind power on the competition situation on the liberalised Finish electricity market.

# 2. The Herfindahl-Hirschman-Index

The Herfindahl-Hirschman-index (HHI) is frequently used to evaluate market concentration. HHI is frequently utilised as an initial screening of the market structure when examining the potential for market power of providers. According to equation 1, the HHI is calculated by adding up the squared market shares of all providers.

$$HHI = \sum_{i=1}^{N} S_i^2$$
(1)

In equation 1, N stands for the total number of suppliers, and Si is the percentage market share of each individual supplier. When there are many suppliers and no one supplier holds a significant portion of the market, the HHI approaches zero. On the other hand, HHI would equal 10,000 for a total monopoly. A market is regarded as unconcentrated if its HHI value is less than 1500.

#### 2.1 Data

Power plant registers from the Finnish Energy Authority and wind power statistics from the Finnish Wind Power Association make up the data utilised for the HHI. The power plant registrations for the years 2005, 2010, 2015, and 2018 are utilised to study these years. The records include information from the year's end, such as the capacity and owner of each power plant in Finland.

#### 2.2 Method

In order to determine the total capacity of each generation firm, the power plants in the register are sorted by company before being used to calculate the HHI. The installed maximum capacity is then used to compute each company's market shares. To calculate the HHI value of the market, as shown in equation 1, the companies' shares of the total capacity are squared and added.

## 3. The Learner Index

Market power in economic research is typically measured using the Lerner Index. Based on the price-cost margin, which is the proportional difference between price and marginal cost as given in equation 2, it is a cost-based approach.

$$L_i = \frac{P - MC_i}{P} \tag{2}$$

P represents the market price, MCi is the business's marginal cost, and Li denotes the Lerner index for firm i. The Lerner index should equal zero when there is perfect competition in the market and prices are equal to marginal costs.

As a result, the Lerner index gets closer to 1 as market power rises. According to David and Fushuan Wen, indices of up to 5% can be used to determine if a market is competitive.

#### 3.1 Data

The Lerner index uses the same power plant records as for the HHI, which provide the capacities and fuel types for all Finnish power plants. Hourly spot prices from Nord Pool are used for price information. Fuel prices are determined using data from Statistics Finland, variable operational costs are determined using data from the Danish Energy Agency, electrical efficiencies are determined using data on the type of power plant as well as hourly electricity production and consumption data from Finnish Energy.

$$MC = \frac{P_{fuel}}{n_{el}} + VOM$$
(3)

The HHI's power plant data, which list the capacity and fuel types for all Finnish power plants, are also used by the Lerner index. Nord Pool hourly spot prices are used to calculate pricing. Electrical efficiencies are calculated using data on the type of power plant as well as hourly electricity production and consumption from Finnish Energy. Fuel prices are calculated using data from Statistics Finland, variable operational costs from the Danish Energy Agency, and variable operational costs from Statistics Finland.

The marginal plant for each hour can be calculated using the hourly production and consumption data as well as accounting for wind and hydro production. The system level Lerner index is the Lerner index for the marginal plant.

## 4. Results

#### 4.1 The Herfindahl-Hirschman-index

The HHI for each analysed year is determined by the capacities of the energy generating businesses and their proportion of the total capacity. In Figure 1, the capacity are displayed by

firm. In the illustration, a market consolidation can be seen to the left. The graph demonstrates that a number of small businesses that were around in 2005 have either shut down or have been bought out by medium- or large-sized businesses. On the other hand, a number of medium-sized businesses have increased their capacity. In the image to the right, we can see how more and more new businesses have been joining the market since 2010. These businesses have modest market shares, although some of them have expanded significantly between 2010 and 2018. The majority of these businesses are newcomers to the market that are tiny wind energy providers. As a result, we can conclude that the market has changed from tiny, outdated businesses being bought out by larger ones or going out of business to small, fresh wind energy businesses joining the market and some of them rising quickly. The leading market players' market shares have largely remained stable. Table 1 demonstrates that there are now 189 enterprises producing power worldwide, up from 110 in 2005. Due to the introduction of numerous small businesses, particularly in the wind energy industry, the overall number of enterprises has increased, despite some being bought. Up until 2018, when a growth was observed, the total installed capacity remained steady. As a result, more manufacturers are now sharing the same amount of capacity, giving each producer a reduced portion of the market.

TABLE I. Installed wind power capacity and HHI 2005-2018

177	2005	2010	2015	2018
Total capacity [MW]	16263	16215	16091	17432
Wind capacity [MW]	82	197	1005	2041
Number of producers	110	120	163	189
Number of wind power producers	7	8	48	76
Share of wind capacity	0.5 %	1.2 %	6.2 % %	11.7
HHI	941	839	649	567

A declining Herfindahl-Hirschman-index across the analysed years, although it was already low in the first studied year, 2005, shows the reduced market shares. As a result, the HHI has continuously fallen below the US Department of Justice's limit of 1500 for moderately concentrated markets. According to the HHI index, the market can therefore be said to be unconcentrated, which denotes a low potential for market power.

Table 1 demonstrates that the HHI declines as both the number of producers and the installed wind capacity increase. By definition, it is possible to anticipate that the HHI and the quantity of producers in the market will be connected.

#### 4.2 *The Lerner Index*

Although the HHI consistently displays low market concentration The Lerner index provides high (albeit wildly fluctuating) values overall for the market power potential, the entire period under study. The high Lerner index over time means that there was a strong possibility for market dominance acted upon in the market. However, the restrictions of the Method must be emphasised before drawing judgements about the market energy is drawn. This will be examined in more detail in the area for debate. The maximum Lerner index has remained steady throughout time, despite a minor increase in the average Lerner index. Additionally, we can observe that over time, the proportion of hours with extremely high Lerner index values (above 0.9) has declined, whilst the proportion of hours with an index of above 0.7 has climbed. The very highest Lerner index values have therefore been appearing less frequently while the high Lerner index values have been increasingly prevalent. The numbers are shown in Table 2.

On the other side, the lower Lerner index values, with values below 0.5, have drastically decreased from 2016 to 2017, with values of just 100 hours per year in 2017 and 2018, compared to 1000 hours in 2015 and 2016. This indicates that the Lerner index was above 0.5 for nearly 99% of the time during the year. Only 86-88% of this number applies to the years 2015 and 2016. The production, capacity, and percentage of wind power in the production of energy have all increased concurrently. But the Lerner index values diverge from the rising wind power figures. As a result, we are unable to conclude from these data that wind power has impacted market power potential.

TABLE II. Summary of results of Lerner index and	nd wind d	lata
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	2015	2016	2017	2018
Average Lerner index	0.643	0.722	0.759	0.766
Lerner index max	0.934	0.975	0.959	0.966
Lerner index min	15.88	-1.81	-0.80	-3.72
Lerner index <0 [hours]	156	20	18	78
Lerner index > 0.9 [hours]	416	543	230	78
Lerner index > 0.7 [hours]	3992	5571	6051	7528
Lerner index < 0.5 [hours]	1268	1079	101	132
Wind over 500 MWh/hours	1044	2260	3972	4676
Average wind share of production	0.035	0.046	0.072	0.087
Hours with wind share > 10 %	67	917	2491	3324
Highest wind production [MWh/h]	868.3 5	1327.0 9	1772.7 7 Activat	1859.9 3 Te Wind

The findings indicate that during a few hours each year, the Lerner index is negative. If the Lerner index is negative, the market price has fallen below the marginal costs of the most expensive plant currently in operation. As a result, several power plants have been selling electricity during these hours for less than their marginal costs, according to the index. Negative Lerner index hours are infrequent and only last for a brief time. The Lerner index gauges the market's short-term status because it only assesses the potential for market power for a given hour. The power producers might not be impacted by brief periods of low electricity pricing in the long run. In the long run, the power plants' losses from not producing could therefore be substantially bigger.

The model and calculations indicate that these plants are still required to meet the demand, and as a result, the Lerner index at the system level turns negative. However, during these hours, the market has not yet encountered market power. According to the data, the Lerner index frequently decreases during the height of wind energy output. This is consistent with, which asserts that market power rises with rising conventional power demand and falls with rising wind power generation. Although the wind power peaks dramatically, the behaviour is not consistent because the index can also decrease without a wind peak and can remain high with only minor fluctuations. When wind energy output peaks, the Lerner index declines, which coincides with a decline in the price of electricity. The Lerner index often remains normal when wind generation is high but electricity prices are stable. This is consistent with, which asserts that market power rises with rising conventional power demand and falls with rising wind power generation. Although the wind power peaks dramatically, the behaviour is not consistent because the index can also decrease without a wind peak and can remain high with only minor fluctuations. When wind energy output peaks, the Lerner index declines, which coincides with a decline in the price of electricity. The Lerner index often remains normal when wind generation is high but electricity prices are stable. For instance, this is evident when examining the spot price, wind power output, and Lerner index for May 2018. Both the price of electricity and the amount of wind energy produced fluctuated significantly in May 2018. The Lerner index decreased whenever the price was at its lowest. Thus, the spot price has a greater influence on the Lerner index than does wind power.

# 5. Discussion

We can see that there have been a lot of new companies entering the market recently thanks to the HHI index. Most of these businesses are small businesses, many of which exclusively work on regional wind energy projects. When merely looking at the capacity, the entry of these enterprises into the market has helped to create a less concentrated market throughout the years. However, the crossownership of businesses and power plants in the market is not taken into account when calculating the HHI. Although in practise there are many instances where the ownership of a company is divided by larger corporations owning specific portions of them, each company is simply seen as its own entity on the market. As a result, the market power of the companies that own shares in other businesses or power plants is more than just their own capacity, and the HHI value reflects a lower concentration than what actually exists. The findings demonstrate high Lerner index values during the whole time

period under study, with an average of roughly 0.7. This would suggest that there is a strong likelihood that market power has been used. However, there are a number of factors relating to the Lerner index's calculating techniques that could possibly contribute to the rationale for the high index values. Koschker and Möst provide many models for estimating marginal costs and explain how the calculation of marginal costs affects the value of the index. As a result, the marginal costs, which are based on estimates, could be excessive and hence have a significant impact on the outcome. Additionally, the findings indicate a seasonal trend with the average Lerner index being highest in the summer. In the summer, the system marginal plants are frequently the least expensive CHP plants. However, the model does not take into account the fact that CHP is not running at full capacity in the summer but rather only a tiny portion of its capacity is being used. As a result, not all of the anticipated CHP capacity may be available, necessitating the use of more expensive plants to meet the demand. Lower Lerner index values and higher system marginal cost would result from this. It should be remembered that a sizeable portion of the energy sold in Finland is produced in CHP facilities along with heat. Despite the fact that the price of electricity is less than their marginal costs as determined by this model, these plants can still make money by producing heat. As a result, CHP facilities in Finland have a significant impact on both the heat and power markets.

Unlike the market for electricity, the market for district heating is not liberalised and deregulated; rather, producers are paid a set price for the heat they generate. With a more stable price, the revenues from the production of heat can occasionally make up for losses in the generation of electricity due to fluctuating pricing. The Lerner index also has the drawback of excluding the necessity for businesses to cover fixed costs. Therefore, the necessity for the enterprises to cover fixed costs can account for some of the gap between marginal costs and pricing.

Due to the frequent cross ownership of enterprises on the Finnish market, the indices display a range of values, and the HHI values that are ultimately obtained may be understated in comparison to reality. The CHP, which is included in the model but is not completely operational in the summer, and the estimated marginal costs may cause the Lerner index, on the other hand, to provide values that are excessively high in comparison to reality. While Lerner is computed based on actual production per hour, the HHI is completely dependent on capacity (which also includes rarely used reserves).

# 6. Conclusions

Numerous small market-share enterprises have entered the Finnish electricity industry as a result of the growth of wind power. Over the years 2005–2018, as a result, the market has evolved towards reduced concentration. The Herfindahl-Hirschman Index indicates that the market has constantly been unconcentrated, with a trend towards even less concentration as more wind power is used.

Based on the four years under examination, HHI has definably dropped as wind power has grown. From 941 in 2005 to 567 in 2018 (where 1500 is the upper limit for moderate market concentration), the HHI values have declined. The Lerner index exhibits a propensity to track the current market price.

The Lerner index value frequently decreases when the spot price declines. No systematic pattern of the Lerner index following the hours with high wind power production can be discovered in the data when looking at the effect of wind power on the Lerner index. On the other hand, if we look at the hours with high or low Lerner index values, we can observe a pattern with wind power. The wind power output has typically been modest, accounting for only 2 to 3% of total production and remaining at or near 240 MWh/h during the hours with the highest (above 0.9) Lerner index values. On the other side, during the negative Lerner index hours, we have seen high average wind power generation because the negative Lerner index values start to appear at 600 MWh/h of wind power generation. Based on this pattern, we can say that adding additional wind power to the system reduces the risk for the greatest Lerner index values (and consequently the largest potential for market power).

To sum up, it can be said that increased wind energy does not translate into increased market power. The HHI contends that as wind power production increases, market competition increases. The Lerner index shows a range of values, most of which are high, with a nudge towards a lower Lerner index with increased wind power. It is advised that market power be further researched and followed up on in the future, when the influence of wind power can be greater, as wind power is still expanding and new projects are always being developed in Finland.

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# 43. Review on wind energy based electricity market price and load forecasting

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## Abstract

Over the past two decades, forecasting the cost and load of electricity has been a major source of concern for experts. Both consumers and manufacturers have had a huge economic impact. Numerous forecasting strategies and methodologies have been created. The driving force behind this essay is to provide an in-depth analysis of power market price and load predictions while keeping in mind the methods and tactics used in science that use wind energy. This review's methodology is anticipating load, price, and historical and structural development of the electrical market technologies, as well as current trends in the production, transmission, and use of wind energy. Like wind According to wind speed, precipitation, temperature, and other factors, power prediction may have some negative consequences on the way the market operates. The market requires forecasting process enhancements, which draw both market participants and decision-makers. In order to do this, this study highlights the key elements of expanding wind energy-based power markets. Quantitative and qualitative analysis is used to discuss and compare the findings. The findings show that, in order to estimate electricity markets' prices and loads with greater accuracy, a growing number of factors must be used as input, and that the trend in approaches changes depending on whether an engineering approach is used or an economic one. In the conclusions, findings are particularly gathered and summarised based on study.

Keywords: electricity price; electricity load; electricity price forecasting; wind energy; day-ahead market; intra-day market; balancing power market

# 1. Introduction

Since the start of the 1990s, competitive market and deregulatory processes have been introduced, replacing the power sector's monopolistic and government-controlled characteristics. Due to the fact that energy is an economically non-storable good and that its production and consumption depend on the stability of the power system, the free-competitive market laws redefine the electricity trade. Globally, the production of electricity from renewable energy sources, primarily wind and solar power, is rising quickly in response to these developments. The ecologically favourable properties of renewable energy sources, which can be indicated by rising energy demand causing global warming in the world, can be linked to this growth.

Electricity generated from wind energy can meet energy demand. However, the weather (such as wind speed, precipitation, and temperature) and industrial operations (such as business work hours, weekdays, weekends, and holidays, etc.) have an impact on the production of electricity. In terms of anticipating related price fluctuations, these characteristics make the commodity of electricity distinctive and distinct from other commodities. It prompts scientists to create fresh prediction techniques. Additionally, electricity price projections (EPFs) have developed into a standard piece of knowledge for energy corporations and researchers in their decision-making processes and schedules in both academic and financial institutions.

As the new techniques are researched, further methods will be explored and developed for EPFs using renewable energy. A contribution made by this essay Analysing the connection between EPF and wind energy in the literature. This essay gives an evaluation of current EPF techniques taking scientific innovation into consideration updated references and wind energy. The improvements in EPF and load methods are Comparatively spoken about, and it ends with the key future works to cover in:

Approaches for forecasting prices and loads for the short, medium, and long terms; Simulation, equilibrium, production cost, and fundamental models for the middle and long terms; Statistical, AI, and hybrid models in the context of time series for the short term; Moving trends of EPF and load techniques that span the fields of engineering and economics; and Working Principles of Electricity Markets as Illustrated by Country-Specific Examples. Market participants and decision-makers are paying more attention to forecasting techniques in the electricity market and for renewable energy sources. In order to achieve this, the purpose of this paper is to present a thorough analysis for electricity markets taking into account price and load forecasting mechanisms through wind energy, one of the most rapidly expanding renewable energy sources as a result of increasing wind power integration into electrical grids. Regarding the established hypothesis, it is seen that different engineering techniques (such as power systems, optimisation, control, and meta-heuristics algorithms) and economic concepts (such as demand, supply, profit, producer, and consumer surplus, and surplus) are used in different forecasting approaches. This review uses a unique methodology that incorporates recent developments in wind energy generation, transmission, and consumption as well as the historical and structural development of electricity markets (such as day-ahead markets, intraday markets, and balancing power markets). The challenges of predicting wind power, i.e., wind power's stochastic nature and its prediction being dependent on weather conditions, such as wind speed, precipitation, and temperature, may have some negative effects on market operations, such as fast fluctuations of wind power and loads in the newly designed power grid. However, applications for wind energy resources demand particularly rigorous and reliable data.

# 2. Electricity Market Mechanism, Components, and Instruments

The day-ahead and intraday markets—commonly referred to as "spot markets"—are part of the short-term electricity market system. But these markets' layouts demonstrate differences. IDMs have gained ground by being worldwide from being national, whereas DAMs have been coupled over the previous few years. Additionally, DAMs are structured as auctions, IDMs, on the other hand, function as trades that allow market participants to balance supply and Short-term supply changes can reduce vulnerability to an imbalance penalty. DAMs are built on projections, and forecasts by their very nature contain inaccuracies.

Particularly, a variety of characteristics and intermittent wind power plant production might be cited as the reasons. However, the forecast is more likely to be correct the closer it is to real-time. Participants in the market can modify their most recent positions thanks to the bilateral basis with continuous trading. In addition to these markets, the BPMs, which are governed by the gearbox system operator (TSO), are ultimately responsible for balancing supply and demand. Security in these markets is taken into account when determining the system stability.

#### 2.1 Day Ahead Markets

A transmission system operator runs DAMs, which are organised marketplaces used for balancing and trading in electricity one day prior to the scheduled delivery date. DAMs include auctions that take place concurrently throughout the day.

By coordinating their selling or purchasing power with short-term price expectations, market participants are able to optimise their own transaction schedule and maximise their earnings. The following list summarises the primary justifications for the necessity of DAMs and their functions:

- calculating the reference price for electrical energy.
- To give market participants the chance to strike a balance by giving them options for purchasing and selling energy for the following day in addition to their bilateral agreements.

- To deliver a balanced system the day prior to the system operator.
- To give the system operator the chance to manage the restrictions from the previous day by setting up bid zones for significant and ongoing constraints.

DAMs are always evolving as a result of institutions, rules, software, and web applications. For instance, a DAM software and optimisation model on the DAM for the Turkish energy industry has just been finished. It has a user-friendly interface design and is flexible and improveable due to the fact that it was totally conceived and written by domestic resources.

#### 2.2 Intra Day Markets

The intra-day market (IDM), in addition to the already existing DAM, Ancillary Services, and balancing power markets, permits nearly realtime trading and gives market players the chance to balance their portfolios in the short term. The IDM serves as a link between the DAM and the BPM and makes a significant contribution to the system's sustainability.

The IDM's functionality alters the role of imbalance-causing factors like power plant failures, changes in the production of renewable energy sources, and unpredictable changes in consumption because they will be eliminated in almost real time, giving participants the chance to balance or minimise any potential imbalances, either positive or negative. Giving the players the ability to assess their capacities will provide more trading space, as they After the DAM closes, you are unable to use it in the IDM. It will assist in the growth of market liquidity. Additionally, it will greatly help the TSO in supplying a system that is balanced before real-time balancing. In terms of institutions, rules, software, and web applications, IDMs are constantly evolving. IDM market designs may differ significantly between nations. For instance, Energy Exchange Istanbul (EPIAS) has been using a new programme called "Intraday Market Software" on IDM since 2016 for the Turkish energy market. For more information on the German IDM, the European IDM, and the Swedish IDM.

## 2.3 Balance Markets

Ancillary services and the balancing power market (BPM) make up real-time balancing. The BPM provides the system operator with extra capacity that can be engaged in a few minutes (i.e., roughly 15 minutes) for real-time balancing. Demand and frequency management are provided through ancillary services. The hourly balancing market prices are established based on the TSO's evaluation of upward and downward regulating power bids during realtime balancing.

The DAM and IDM provide the TSO with a market that has balanced production and consumption volumes, although there are realtime variations. The equilibrium is upset, for instance, when a power plant is out of commission or when heavy consumption forces the plant to shut down (start up).

Regarding BPM for the Turkish electrical sector, for instance:

- Every market participant who is taking part in the BPM must submit their capacity options.
- Balancing units must participate in the BPM if they can receive or load independently in a few minutes (about 15 minutes), contains further details regarding the European BPMs.

# 3. Research on Electricity Market Instruments by Country

## 3.1 Electricity Price

The law of supply and demand curves governs the market clearing price (MCP) for electricity. The DAM, which is run by the system operators of the nations, is the appropriate location for this. The supply/demand curves are constructed analytically using the hourly offers that vendors and buyers submit for the following day. The MCP is determined by where the supply and demand curves cross. While the purchasing and selling amounts are referred to as the equilibrium quantities of electricity, the MCP multiplied by the equilibrium quantity determines the volume of power traded. But it is difficult to predict energy prices since price series exhibit traits including variation, non-constant mean, strong outliers, and volatility.

Seasonal pricing effects; Mean reversion; Volatility caused by fluctuations in fuel prices, load uncertainty, power outages, market power, and market player behaviour; Correlation between electricity load and price. More in-depth information can be found for a number of countries, as well as for the Turkish electricity markets, for the electricity markets in England and Wales, for the electricity markets in the Nordic region (Nord Pool), for the electricity markets in New Zealand, for the electricity markets in Denmark, and for the electricity markets in the United States.

#### 3.2 Electricity Load

The operation of power networks relies heavily on forecasting the electricity load, which includes projections on multiple time scales (such as minute-by-minute, hour-by-hour, and annual).

The dependability analysis, dispatch planning for generating capacity, and operation and maintenance schedules for power systems are only a few decisions that are based on load projections.

The deregulation and open competition in the electric power sector have enhanced load forecasting's feasibility and significance globally. Since forecast errors may potentially affect market shares, profits, and shareholder value, an accurate expected load is essential information for the EPF. However, because the load series is nonstationary and variable, forecasting methods for the electric load are becoming more challenging. This complexity is brought on by timevarying pricing, price-dependent loads, and the dynamic bidding tactics of market participants. Therefore, more advanced forecasting tools are required for electrical power systems, and the economic impact of prediction inaccuracies serves as the driving force behind more precise forecasting approaches. There has, however, been a significant amount of research done.

Electricity should also be stored or used as soon as possible once it is generated. Electricity markets, through system operators, exist to allocate transactions amongst market participants since it is expensive to store electric power. This process offers a potential method of load dispersion, releasing networks from heavy loads. The emphasis of this review is wind energy as a source of renewable energy. Wind energy output is significantly influenced by weather factors such as temperature, precipitation, and wind speed.

The nations that generate a sizable portion of their electricity needs from wind energy (such as

Spain, Denmark, and Germany) and have wind energy potential (such as Turkey) ought to consider this energy source as a means of reducing global warming. For further information about other countries, and for the Turkish power markets.

# 4. Discussion on Forecasting Models on Electricity Markets

Around the world, day-ahead, intra-day, and balancing markets determine the price and load of electricity; however, research shows that, despite the fact that its data are frequently made available to the public, market clearing price forecasting is more difficult than load price forecasting (e.g., fuel prices, equipment failures, and the fact that the nature of the market clearing price depends on the hourly loads creates this complexity). The complexity of predicting the price and load of the electricity market depends on the growing number of variables used as input for greater accuracy. As a result, the trend in approaches shifts to more advanced tools, such hybrid models, as demonstrated and described in this paper.

It is clear from the papers analysed in this review that renewable energy sources should be preferred, changing the structure of electricity markets for better environmental conditions with low-carbon levels. This is in addition to the explanation of the operating principles of the electricity market. All nations can use incentives and supply security as tools. Over the past 20 years, numerous techniques and models have been created for the EPF of markets. Autoregression, moving average, exponential smoothing, and its variants have proven to be insufficient due to the stochastic and nonlinear character of statistical models and price series. Artificial intelligence models are adaptable, non-linear, and able to capture these characteristics. Since artificial neural networks are more precise and durable than autoregressive (AR) models, they excel in short-term forecasting and are effectively applied to the power market. The study employs models of artificial neural networks to show how strongly the price of power affects trend load and MCP. Artificial neural network models are used by Singhal and Swarup to investigate the relationship between electricity load and price in the MCP.

# 5. Conclusion

Around the world, the power sector is expanding quickly, and one of the most important factors in the generation of electricity is the use of renewable energy sources. Additionally, renewable energy is environmentally favourable (i.e., a significant decrease in emissions helps to slow global warming). Consequently, utilising wind energy more effectively is a problem to supply electricity for electrical markets. The electrical market mechanisms have had to contend with regulation procedures created by decision- and policy-making processes for the past 20 years. The main driver of electricity price reductions and technologies that can reliably meet demand is competition. However, the drawbacks of this commodity include the price peaks and volatility that are brought on by different environmental and commercial variables. These limitations motivate researchers to develop more effective instrument, technique, solutions. The most recent methods for predicting electricity prices and load are compiled in this review paper, together with a discussion of their advantages and disadvantages. Nevertheless, the markets for trading electricity are the bilateral transactions are becoming more complicated, with novel types of contracts or regulated markets as a result of a law governing free market competition. the unaffiliated Controlling gearbox systems for each distinct market is the job of gearbox system operators. all transmission networks collectively. Market clearing powers the price mechanism. Price, which is derived from the law of fixed supply and demand curves on the markets for the next day. Transmission system operators correct price variations brought on by supply and demand forces in order to balance electricity markets. Additionally, the intra-day markets provide as a link between the balancing markets and day-ahead markets. Market players have the option to sell or acquire the necessary power in the intra-day markets if they do not sell all of their power or take their positions in the day-ahead markets.

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# 44. An overview on reactive power supervision in deregulated energy markets

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## Abstract

Operation and control tactics have changed paradigms as a result of the restructuring" of the electric power" industry over the past ten years. Voltage and frequency control are two examples of operations that are now viewed as separate services and are frequently controlled and reported for individually. These activities were previously thought to be a part of the integrated energy supply. The administration of reactive" power services in globally deregulated electricity markets" is examined in this study. Several different approaches to managing reactive power within" the deregulated market" environment are shown by the review. While there are enough financial mechanisms in place in many markets to reimburse service providers for their labor, several others still manage reactive power" through regulatory frameworks" and technical operation requirements.

Keywords: Deregulation, ancillary services, reactive power management, reactive power tariffs

## 1. Introduction

Due to technological and financial limitations, transmission line designs can only transmit a certain amount of power. Reactive-power flows must therefore be reduced in order to increase the amount of real power that may be transferred via a network. In order to satisfy customers' equipment voltage ratings, enough reactive power needs to be provided locally in the system to maintain the bus voltages within nominal ranges. In deregulated energy markets, the Independent System Operator (ISO) must provide provisions for reactive power assistance in order to meet the contracted transactions securely. The perceived demand conditions, load mix, and availability of reactive power resources should all be taken into consideration when purchasing reactive power services. The resources for reactive support, such as synchronous generators, synchronous condensers, capacitor banks, reactors, staticvar compensators, and FACTS devices, are frequently owned by independent generators or customers, and the ISO must enter into contracts with them for such service.

Reactive power support was a function of the system operator's duties in vertically integrated electricity systems, and the costs associated with delivering such services were charged to customers as part of the energy bill. Reactive power management, however, is handled and paid for separately in deregulated systems, along with a number of other auxiliary services. However, depending on how the contracts are written and the markets are run, different deregulated energy markets have different reactive power management and payment procedures.

Typically, the ISO contracts with reactive power suppliers to offer their services. According to the NERC's Operating Policy-10, only reactive power supplied by synchronous generators is regarded as an ancillary service in the US and is eligible for payment. The Australian and British markets share the same characteristics. The Australian market similarly views synchronous condensers' reactive power as an ancillary service.

On the other hand, payments for reactive electricity services are not allowed in the Nordic countries' deregulated markets.

Examples include Sweden, where network companies are in charge of managing reactive power, and where guidelines from the ISO prohibit the exchange of reactive power between various network voltage levels and transformers. Individual entities, such as municipal and regional networks, must plan for their own reactive power in order to meet these criteria. The network firms in the Netherlands are similarly required to handle their individual reactive power needs. However, these businesses buy reactive electricity close to home through exchanges with other network businesses or through bilateral agreements with generators. Only the reactive power capacity of the generators that have been hired for the reactive power service is compensated. Reactive energy is not compensated in any way.

Here, we aim to investigate how reactive power is handled and financially compensated for in various deregulated energy markets across nations. Various difficulties relevant to the establishment of market-based mechanisms for reactive power and the best procurement schemes for reactive power by the ISO have been pointed out in prior related studies by the authors.

In addition to discussing how these markets function, the current work aims to highlight the diversity among the various systems in how they approach this crucial technical problem of reactive power management. However, due to space constraints and the fact that material was not always readily available, this paper's scope was constrained. We make an effort to widen our coverage of globally deregulated markets while also attempting to cover some of the significant advancements and market models.

# 2. USA

In its White Paper on the Proposed Standards for Interconnected Operations Services (IOS), the North American Electric Reliability Council (NERC) announced that only generation sources would be permitted to offer reactive power as a IOS" or supplementary service. The other organizations offering reactive support are not to be regarded as IOS and are not entitled to any payment. However, the operating authority organizes the system's employment of static reactive supply devices. In order to ensure that the reactive power output of the generators during emergency situations does not fall below the reactive capability, all synchronous generators must be running with their excitation system in automated voltage control mode. This is especially true when the generators are running at levels beyond their rated actual power and the reactive power production is constrained by the armature current heating restrictions. If the generator terminal voltage drops in such a case (due to various eventualities), the reactive output from the generator would be significantly decreased, endangering the stability of the system.

#### 2.1 New York ISO

Reactive power support services are offered by the New York ISO (NYISO), and their costs are based on embedded costs. NYISO instructs generating resources to generate or absorb reactive power to keep voltages within acceptable ranges when they are operating within their capacity limits. By adding up all of its payments to the suppliers who offer the assistance, the NYISO determines the cost of reactive power support. Along with any applicable lost opportunity costs and balance account adjustments from the prior year, it also includes the overall yearly embedded cost. The yearly fixed charge rate associated with resource capital investment, the present capital investment of the resource (generator or condenser) assigned for supplying reactive power support, and other operating and maintenance costs are used to calculate the annual embedded cost component.

When a generator is instructed by NYISO to lower its real power output level, a component of payment accounting for the Lost Opportunity Cost (LOC) is given to the generator. The following variables form the basis of the LOC calculation:

Long-term based marginal price (LBMP) in real time, the old and new dispatch points for real power, and the bid curve of the generator supplying reactive power service. The calculation of a generator's LOC, which reduces its real power production to provide more reactive power service, is shown in Figure 1. Even if the generator generates less energy, it nevertheless saves some generating costs despite the fact that its true power output is reduced. Equation (1) can be used to explain the generator's decreased income.



Fig. 1. Method for calculating Lost Opportunity Cost by NYISO [5]

$$\Delta R = P_{RT} \left( D_1 - D_2 \right) - \int_{D_2}^{D_1} f(\mathbf{P}) \cdot d\mathbf{P}$$
(1)

The first term in (1) denotes the revenue lost by the generator while backing down its real power output from D1 to D2, and the second term denotes the corresponding reduction in generation cost. Note that  $\Delta R$  also equals the savings to the ISO. The saving of the generator ( $\Delta S$ ) from reduced real power output can be given as,

$$\Delta S = B_1 (D_1 - D_2) - \int_{D_2}^{D_1} f(P) \cdot dP$$
 (2)

The LOC of the generator equals to the difference between equation (1) and equation (2), *i.e.*,

$$LOC = (P_{RT} - B_1) \times (D_1 - D_2)$$
(3)

#### 2.2 California ISO

In the California system, the ISO hires dependable must-run generating units to provide reactive power support services on long-term contracts. After the real power market has been settled and the energy demand and schedules are understood, the actual short-term requirement is calculated on a day-ahead basis. The ISO then uses system power flow analysis to determine the amount of reactive power that is needed in each site. Contractual generators and the local transmission operators are given daily voltage schedules. The generators must deliver reactive power between 0.90 lag and 0.95 lead in terms of power factor (Figure 2). The generators are financially reimbursed for reactive power absorption orgeneration over theselimits, including a payment if they are obliged to reduce their real power output.



Fig. 2. The mandatory (no payment) reactive power requirement and the ancillary service component that receives financial compensation in the California system

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#### 2.3 PJM Interconnection

In 1997, the Pennsylvania-New Jersey-Maryland (PJM) interconnection reorganized its activities and became the ISO. According to the Market Monitoring Unit's reports, PJM identified reactive power as an additional service and separated it into two separate components. The reactive capability at rated capacity of a generator made up the first component, and the reactive capability at reduced generator output levels made up the second. Reactive power supply and voltage control services must be delivered directly by the various transmission service providers. In turn, the transmission service providers have established the tariff rates for their clients, in this case, load-serving businesses inside or outside the zone. The client pays a fee that is proportional to the total generation owner's monthly income requirement and the amount of network usage for the first component, or the reactive capability at rated capacity. Regarding the second component, generators are compensated for the opportunity costs they incurred as a result of lowering their real power output in order to increase their production of reactive power. The opportunity cost is equal to the locational marginal price less the generator's offer for each MW that they withdraw, and it is only paid to generators that are instructed to operate in this manner.

#### 3. In Europe

## 3.1 The UK

#### 3.1.1 Reactive Payment Plan

The National Grid Company (NGC) acts as the ISO in the U.K. power market. All generating units with a power generating capacity more than 50 MW are required by the Grid Code to offer a basic (mandatory) reactive power service. The generators must agree to a Default Payment Mechanism (DPM) in order to receive payment for this service. By framing their bids to represent the price they believe their service is worth, the generators can also provide the required reactive power service through the tender market. Obligatory Reactive Power Service (ORPS) is a word used to describe this method of complying with the required Grid Code through a market mechanism. The amount of money a generator could make by delivering reactive power varies depending on how many generators can do so within a zone and how

much of a need there is. Additionally, generators that can provide reactive power in excess of what is required by the Grid Code can provide an Enhanced Reactive Power Service (ERPS). When the plan first began in 1997/98, the Default Payment Mechanism was based on two components, with an 80:20 ratio between the capability payment component and the actual utilisation based payment component. The capability component of this ratio underwent a staircase phasing process, and since April 2000, the ratio has been 0:100. The Default Payment Mechanism is based only on metered reactive usage. In accordance with the new arrangements, NGC has formalized a reactive power market by inviting tenders, which may be for ORPS or ERPS. Any potential service provider may submit a tender, regardless of whether they currently receive payments under the DPM agreement or not. The provider is better able to guarantee a certain level of money in this way. As opposed to the DPM, the bidders have more flexibility to establish payment conditions that are more cost-reflective of the actual service rendered because they can specify pricing for capacity and utilisation. There are two annual tendering processes that begin on the first of April and the first of October, respectively.

#### 3.1.2 The Tender Market's Bid Offer Structure

Reactive power service providers' tender proposals are divided into two parts:

- a) The pricing component for capability (see Figure 3).
- b) The component of utilization price (see Figure 4).

A reactive service provider has the option of bidding pricing for both leading and lagging MVAr capacity or simply one of them when submitting a capability price proposal. Additionally, it has the ability to bid for two different forms of capability prices: synchronous capability prices and available capability prices. A possible cost function for synchronized and available capability is shown in Figure 3. Generators may provide up to three incremental costs for both leading and lagging MVAr capabilities for each type of capability pricing. The requirements are the same as above for utilisation bid price, and up to three incremental values can be provided for leading and lagging Mvar (Figure 4).



Fig. 3. Tender bid price structure for synchronized and available reactive power capacity



Fig. 4. Tender bid price structure for reactive power utilisation

The bidding trends in the reactive power tender markets for ORPS and ERPS spanning the periods April to September 1999 and October to March 2000, respectively, have been evaluated.

The analysis leads to the following conclusions:

- 95 producing units have a reactive power agreement with NGC as of April 2000 as part of the UK reactive power tender market system.
- None of the bids were for ERPS; all were for the provision of ORPS. Receiving bids for ERPS would be advantageous for NGC.
- It was clear that at least 50% of the bidders wanted to be paid more for their reactive power capacity while still mostly adhering to the DPM payment profile.
- A few bidders chose a straightforward available capability payment structure that reflected a linearpayment rate per MVAr of available reactive power.
- Some provided a flat" payment rate based on available capability.
- Little incentive was provided by this sort of tender for NGC to take these generators in order to sustain capability.
- The payment structure was chosen by the majority of tenders based on steeper incremental capabilitypricing for larger

MVAr outputs. These tenders clearly indicate the preferred operating range of the generators.

- In a few of the marginal circumstances, NGC may choose to accept or reject a market agreement due to the high incremental capability prices.
- While many bidders requested to be paid based on the hours synchronized, the majority of bidding submissions included capability prices for hours available.

#### 3.2 Sweden

Bulk power flows through long distance transmission lines from the north, where the majority of the generating is located, to the south, where the majority of the load centers are, are what define the Swedish electricity system. Reactive power should be supplied by local sources because it cannot be transported across such long distances. While the regional and local network firms run the sub-transmission and distribution networks (130 kV and less), Svenska Kraftnät controls the national grid (400 kV and 220 kV) and fulfills the ISO's duties. In Sweden, the provision of reactive power services is required, and there is currently no plan in place to compensate those that supply these services financially. Svenska Kraftnät gives instructions to the national grid's reactive power exchange. Reactive power flow between different grid components should be kept near zero," according to recommendations. The ISO is entitled to receive reactive power from spinning generators that are directly connected to the national grid. Voltage control in each region is the responsibility of the regional network corporations. The regional network operators produce as much static reactive power as they can under normal circumstances. Large generators are typically designated for usage in emergency situations and are rarely employed for secondary voltage regulation. With a steady operating point that takes vibration and losses into account, such machines run at a constant reactive power output.

1) Official Grid Transfer Agreements for Reactive Power:

Svenska Kraftnät enters into formal agreements for reactive power exchange with independent generators and regionalnetworks fortransactions over the network. Although there are times when regional networks may also be involved, most power producers are involved in the agreement for supplying electricity into the national grid. The following list of common agreements includes some:

• To beable to inject and absorbreactive power within thefollowing parameters, a hydro unit mustbe directlyconnected tothe national grid.

Reactive Injection = 
$$\frac{l}{3} P_{Max}$$
  
Reactive Absorption =  $\frac{l}{6} P_{Max}$ 

• For the capability of reactive power injection to be maintained within the below-mentioned limits, a thermal unit directly connected to the national grid is necessary (mandatory). It does not, however, need the absorption of reactive power.

Reactive Injection = 
$$\frac{1}{3}$$
 P<sub>Max</sub>

• In order to preserve the abilityto injectreactive powerdependent on the instantaneous real power injection as indicated below, a regional network withan agreement to inject real power into the national grid is required.

Reactive Injection = 
$$\frac{1}{3}$$
 P<sub>instantaneous</sub>

Reactive electricity from thenational gridcannot be required tobe absorbed. Additionally, there are no requirements for a generator that is connected to the local grid.

• a regional network that has an agreement to draw actual power from the national grid; reactive power injection or absorption into or out of the national grid are not necessary.

## 3.3 Finland

Finland's electricitymarket wasopened tocompetition in 1995 by theElectricity MarketAct and the point of entry tariff, and it becamea price areaon theNordPool exchangein June 1998. In order to maintain system voltages, the Finnish ISO, Fingrid, supplies reactive power in accordance with the general supply guidelines for reactive power. Reactors and capacitors are used to control the main grid's voltage level. The transformers' tap changers regulate how much voltage is applied at each step of voltage.

1) Reactive electricity Reserve Service: Fingrid is also in charge of ensuring that the Finnish electricity system has sufficient reactive power reserves. This is accomplished both by using internal resources and by collecting reactive reserves from outside sources. As of right now, this reactive power reserve provision is a required service. By 2002, a tariff mechanism for monetary remuneration for this service will probably be established:

According to the regulations, generators with a rating of more than 10 MVA must keep reactive power reserves when the power system is operating normally:

- All reactivecapacity, with the exception of that used by transformers and the plantitself, should be accessible as momentary reserves and essential for generator slinked to the 400 kV grid.
- The required instantaneous reactive power reserve for generators connected to the 220kV and110 kV grids should not be less than 50% of the calculated reactive capacity, which corresponds to a power factorof 0.9. The remainder can be used as a paid service.
- Half of the reactive power intake capacity at the generator's voltage level must also be set a side as a reserve for transient disturbances for generators linked to the grid at voltage levels lower than 110 kV.

# 4. Australia

Only the reactive power provided by synchronous generators and synchronous condensors is recognized by the Australian electricity market and its ISO, the National Electricity Market Management Company (NEMCO), as ancillary services, and financial compensation is made available to them for their service provision.

All providers of supplementary reactive power services are qualified to receive the availability payment component, which rewards them for being ready to respond to customer requests. Additionally, the synchronous compensators also get an enabling payment component when the ISO makes their service available for usage. A synchronous generator, on the other hand, is compensated based on its opportunity cost and paid when it is prevented from acting in accordance with its market determinations. Figure 5 displays the entire cost for the reactive power service.

A. Services for Mandatory and Incidental Reactive Power

Reactive power from generators is divided into two categories: Reactive power support that is required and Reactive power as an auxiliary service.

The generators must deliver reactive power within the operational power factors of 0.9 lagging and 0.93 leading, as shown in Figure 6. Beyond this required component, the generators are expected to provide the auxiliary service component. However, a fraction that lies outside of the ancillary service component is left unspecified.



Fig. 5. Payment for Reactive Power



Fig. 6. Generator Reactive Power Definitions in the Australian Market

The following describes the fundamental voltage control strategy used by NEMMCO:

- The reactive power need in the system is calculated using a variety of energy management system functions (such load flow analysis).
- Reactive power support components including capacitor banks, reactors, and SVC are turned on and off as needed.

- The next step is to utilise the existing online generators' reactive power support to the degree that their regular output is not restricted. Here, the required amount of reactive power must also be supplied by the generators that were not hired for auxiliary services. Reactive power suppliers may be asked for amounts above the minimum requirement in exchange for payment.
- Then, from a merit order based on enabling prices, selected synchronous compensators for the particular area are activated.
- The ISO considers restricting the units' ability to generate actual power if additional reactive power is needed.
- Market trades may be restricted if the total reactive assistance available from all sources, as mentioned above, is insufficient to guarantee system security in certain circumstances.

# 5. Conclusion

Provision for reactive power assistance and developing suitable price mechanisms for that are significant issues in deregulated electricity markets. The management of reactive power in certain of the deregulated electricity markets has been the subject of an examination in this essay.

The service is offered by providers in the British reactive power market, and their bids include a capability price component and a utilisation price component. In New York, a payment for lost opportunity cost is also determined in addition to the payment for embedded cost. The required service and ancillary service components of Australia's reactive power service are both provided, and the service is paid for in three ways: availability, enabling, and compensation. However, in many deregulated power networks, independent producers continue to support reactive power without being compensated by the ISO.

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# 45. Shipboard power system intelligent protection system design

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## Abstract

This study suggests a breaker switching technique for a typical naval power system's selective protection. Using backpropagation neural networks (BPNN), A mapping link is created between the breaker switching mechanism and the fault characters. A detailed explanation of the design process for the BPNN intelligent protection was provided.

. The success of the suggested protection plan was demonstrated by the establishment of a close-loop testing system that included fault detection software and power system simulation. Additionallythe AC radial distribution system has developed and tested an intelligent protection prototype. Further testing is performed with the Hypersim real-time close-loop testing technology for a more complex system.

Keywords: distribution network, BP neural network, intelligent protection scheme, breaker switching approach, shipboard power system

# 1. Introduction

Time-overcurrent protection is used in the conventional shipboard power system (SPS) to satisfy the requirements for selectivity and dependability. The time-overcurrent principle's use relies heavily on the selective protection of nearby grade breakers. Even if shipboard cables are short and have low impedance, after a short-circuit fault, the current values of the neighboring grade breakers approach to the point where it becomes very difficult to determine the correct breaker settings. Achieving selectivity requires the use of suitable delaytime factors. Even if there is less grading in the power system and a shorter delay period, the devices under short-circuit conditions will be less affected. On the other hand, the delay time in a system with more graded power Solutions have been proposed based on fault location studies. The SPS is currently protected by the time-overcurrent concept. In order to establish the best balance between selective and quick protection, overcurrent relay coordination

has been proposed [2-4]. One potential remedy that can detect internal or exterior defects occurring within the designated zone is the current differential scheme. To satisfy the need for backup protection, a large area differential protection has been suggested [5-7]. Breakers can be controlled in a certain manner following the fault's detection to characterise every safeguard. While time-overcurrent protection uses the current passing through a single breaker to discover problems, the current differential technique uses the current difference of two or more breakers.

The format of this document is as follows. The breaker switching technique, which is a perfect protective measure to achieve the selectivity with regard to SPS, is introduced in Section 2. In order to achieve the mapping from short-circuit faults to the breaker switching strategy, An intelligent protection system based on BPNN is presented in Section 3 pro. Section 4 displays simulations of an SPS under different conditions to verify the adaptability of the protection mechanism. Section 5 compares intelligent protection with time-overcurrent protection and details the testing of the intelligent protection prototype.

#### 1.1 Breaker Switching Strategy

Choosing a breaker switching strategy entails knowing what to do with the breakers in the event of a short circuit. It serves as the cornerstone upon which an efficient protection plan is built. A sensible approach to switching breakers is to use a breaker that can promptly cut off a short-circuit fault and minimize the amount of power loss. Because the structural features of the SPS distribution and transmission networks differ, the protection plan must be divided into distribution network and transmission network breaker switching procedures. Concerning the current radial distribution system. In order to maintain power supply on the non-fault lines, the distribution network's breaker switching strategy must disconnect the breaker nearest to the fault location along the upstream line.

Two power plants, each with two generators, make up the system. The busbar breaker Cb24 connects generators G3 and G4, while the busbar breaker Cb23 connects generators G1 and G2. Additional applications of this structure can be made to multi-ring or ladder networks. Every electricity plant has several distribution hubs. One distribution center is utilized here to illustrate the concept, keeping in mind that all distribution centers use a similar breaker switching technique. Figure 1's dashed lines depict the distribution center L. Assuming that there is a short-circuit defect at f1, the transmission network is affected. The generator G1 nearest to the failure point can be easily located thanks to the transmission network breaker switching method.

If there is a short-circuit problem at f3, the distribution network will be affected. Breaker Cb16 is the upstream breaker nearest to the fault location f3, based on the distribution network breaker switching method. Cb16 will thus be disconnected. Analyses similar to this can be applied to various breaker switching procedures used to address other issues.



Figure 1 Typical shipboard power system.

#### 1.2 Defense Plan that Uses BPNN

To provide protection for SPS in line with the selected breaker switching strategy, an integrated protection unit can accurately locate the faults and provide action signals to the breakers. As far as the breakers are concerned, there is less fluctuation in the instantaneous values of the short-circuit currents when short-circuit failures happen at different locations within the transmission network. As a result, using the current numbers to precisely establish the fault position is difficult. When either f1 or f2 is in short circuit, the fault currents via the generator and busbar breakers are similar under the same generator capacity and settings, as shown in Figure 1.

The following issues will surface if an integrated protection unit is used throughout the distribution network: (1) Reduced dependability of the SPS's instantaneous short-circuit protection because of the sheer volume of data that must be handled by a single deputy or program; (2) Sluggish data processing as a result of data overload; (3) Vulnerability as a result of the communication links for protection being so complex. As a result, the individual distribution centers might split the distribution network into multiple zones. An intelligent protection device is installed in each center to handle localized short-circuit failures.

The breaker may determine whether a fault occurs in its protected region based just on the current passing through it, in accordance with the time-overcurrent concept that is currently in place. Nevertheless, there will undoubtedly be overlap between the lines that the upstream and downstream breakers protect. Conversely, intelligent artificial neural networks can be used to handle the difficulty of classifying certain kinds of errors.

One way to characterize the intelligent protection principle is as follows: First, each short-circuit defect's characteristics, as fault F1 in Figure 2, should be retrieved; Second, the acquired fault characters are preprocessed to create the associated breaker switching strategy, denoted as y1, by establishing the fault characteristic vector as x1. In a similar vein, it is possible to determine the characteristic vector (xi) and matching breaker switching technique (yi) for fault Fi. A characteristic space is made up of all the characteristic vectors and is written as x=(x1, x2,..., xi,...), and a breaker switching space is made up of all the corresponding breaker switching methods and is expressed as y=(y1,y2,..., yi,...). Finally, the mapping from x to y is made possible by the clever method, as seen here.



Figure 2 Distribution network of AC power system.

The performance of a neural network is significantly influenced by the inputs that are chosen. An excessive number of elements in the input layer slows down the protection's calculating speed. Ples are insufficient since certain specific fault types cannot be accurately diagnosed. Superfluous training samples will add to the burden and undermine the ability to be generalized and tolerated. Eventually, the characteristic space and the breaker action space can be mapped in the right ways.

#### 1.3 Choice of Input Layer Elements

Traditional time-overcurrent protection uses the root mean square (rms) of the three phase currents I=(Ia, Ib, Ic) as detection signals because of the apparent oscillations in the short-circuit current that make them simple to detect. The corresponding waveforms of the Brk6 current rms are shown in Figures 4 and 5. The maximum of the three-phase and phase-to-phase short-circuit faults at F is denoted by I\_Brk6M, whereas the rms of the Brk6 three-phase currents are I\_Brk6a, I\_Brk6b, and I\_Brk6c.



Figure 3 Flow chart of intelligent protection method

A typical shipboard distribution network is presented in Figure 2, with the distribution hubs indicated by dashed lines. The following actions can be taken to achieve distribution center I's intelligent protection: First, with a commercial simulation system such as PSCAD/EMTDC, a high fidelity model of the shipboard power system has to be constructed. Second, fault characteristic vectors for the specified faults can be acquired through simulations. In the meantime, by developing the breaker switching strategy based on the fault sites, training samples for neural networks can be produced. Thirdly, the proposed BP neural network needs to be trained. In the end, the system's fault detection and breakers' control must be handled by the trained BP neural network.

It is found that differences in the phase current rms are caused by different types of short-circuit failures. When a phase-to-phase short-circuit fault arises, the rms of the non-fault phase current appears to be small, which is unable to represent the fault.

Thus, it is It is recommended to treat twophase current rms as at least characters. The selection of training samples becomes more complex if the neural network inputs consist of two or three phase current rms because three-phase and phaseto-phase short-circuit faults need to be taken into account. Consequently, there is a chance that the neural network's training process won't converge, and in the interim, its capacity for generalization will be diminished.



Figure 4 Current rms of Brk6 under three-phase fault F6.

#### 1.4 Design of Neural Network

The vectors representing the fault characteristics gathered from each breaker serve as the neural network's inputs. Step signals are used by the neural network's outputs to directly operate the breakers. The inputs and outputs control the hidden layer neurons that affect the network's capacity for generalization and computation speed. Although more hidden layer neurons can decrease identification error and boost approximation precision, they can also limit generalization and raise computation costs [8–9].



Figure 5 Current rms of Brk6 under phase-to-phase fault F6.

The maximum Brk6 three-phase current rms has a similar waveform in many short-circuit fault modes, particularly in the early stages of the fault. As a result, the neural network's inputs can be the maximum three-phase current rms of each breakers. It is anticipated that this selection will detect defects in diverse fault modes and operating conditions of the power system. Additionally, this approach simplifies the neural ICCIDE\_2023

# 1.5 Selection of Training Aamples

rms of each breakers as an input.

when compared to using the two-phase current

All of the loads in the distribution center Brk1-Brk10 are powered on, and all of the breakers are activated throughout the simulation system's training sample collection process. The goal is to make sure that all potential problems that may occur in the distribution center have their distinctive information collected. It is important to consider circumstances with maximum and minimum generating capabilities since short-circuit currents change depending on the operating conditions. In the two scenarios mentioned above, three-phase short-circuit faults have been simulated, with samples collected from 2 ms to 10 ms following the fault at a frequency of 2 kHz collectively. Twenty input groups, each containing ten characters that reflect the maximum three-phase current rms of Brk1 through Brk10, have been set aside.

Three Instances When the SPS runs under different conditions, the protective system should offer efficient fault identification and isolation. The suggested intelligent protection system has been integrated with a simulation model in Figure 2 that has been set up in PSCAD/EMTDC [10]. The following conditions have been tested through simulation:

A. Varieties of Fault Types We have simulated both phase-to-phase and three-phase shortcircuit faults in a neutral-line disconnected distribution system.

B. Various Power Source Capabilities The requirements for the highest and lowest power source capacities have been considered.

C. Modification of Configuration The breakers of certain loads will be disconnected when they are not in use under various operational conditions. The associated inputs of the BPNN will now maintain and load down, have been considered.

#### 1.6 Short-circuit Resistance

Resistive short-circuit faults, which reduce short-circuit current by fault impedance, exist in addition to metallic short-circuit faults. Regarding conditions A through C, the intelligent protection system has identified the errors and advised the relevant breakers to take the appropriate action in order to isolate the errors. The clever protection system won't interpret load disruptions as a malfunction. The intelligent protection's detection time will increase as short-circuit resistance rises. Once the resistance has been surpassed, the problem is undetectable. When there are short-circuit faults with short-circuit resistances of  $0.01\Omega$  and  $0.1\Omega$  at F3, Figures 6 and 7 display the Brk3 short-circuit current rms and the action signals of the breakers. Additionally, simulations of compositive circumstances such as phase-to-phase short-circuit faults at varying power source capacities have been conducted. With the exception of high resistance short-circuit faults, the intelligent protection system can handle the majority of scenarios. To manage this circumstance and stop the intelligent protection system from failing, time-overcurrent protection can be configured as a backup safeguard.



Figure 6 Current rms and action signals under three-phase short-circuit fault F3 at resistance of  $0.01\Omega$ .



Figure 7 Current rms and action signals under three-phase short-circuit fault F3 at resistance of  $0.1\Omega$ .

#### 1.7 Testing

DSP has developed an intelligent protection program. Included are programs for fault detection and sample training. The intelligent protection prototype consists of three modules: digital output isolation, fault detection, and analog input regulation. The ac radial testing system shown in Figure 8 was utilized to gather findings from functional testing of the prototype. Breakers Bk1–Bk5 in the dashed lines are controlled by the protection prototype, and fault H6 has current differential protection in place.



Figure 8 AC radial testing system.



Figure 9 Currents of Bk4 and Bk5 under three-phase fault H4.



Figure 10 Current and action signal of Bk4 under three-phase fault H4.

As seen in Figure 11, The Hypersim real-time close-loop testing technology has been used to

conduct more tests. The simulation model for Hypersim is based on Figure 2. The intelligent protection prototype connects the D/A and D/I interfaces to the Hypersim real-time simulation system. The prototype receives the largest root mean square of the three-phase currents from Brk1–Brk10 via D/A connections. The prototype sends action signals to the simulation system via D/I interfaces in order to control the relative breakers following BPNN's fault detection.



Figure 11: Closed-loop testing system in

Three-phase short-circuit faults, denoted as H1-H6, have been simulated. Figures 9 and 10 display the associated waveforms of Bk4 and Bk5 under fault H4. Bk4 and Bk5's phase currents are represented by Figure 9 shows CH1 and CH2. The phase current and the Bk4 action signal are shown as CH1 and CH2, respectively, in Figure 10. When a problem occurs at H4, currents across Bk4 will rise, enabling the prototype to identify the fault and send an action signal to Bk4 in less than two milliseconds. After the built-in action time of the breaker, the are left on during the fault. The currents return to normal through Bk5. Short-circuit currents will be turned off in 25 milliseconds. The extra breakers The short-circuit faults F1-F10, which arise when only G1 is functioning, have been tested via simulation. The results of fault F5, which occurs in the simulation at 0.1s, are shown in Figure 12.

Figure 12 shows the action signal and the three-phase short-circuit fault F5's currents rms for Brk4 and Brk5.

Figure 12's waveforms, which are arranged top to bottom, show the Brk5 action signal, Brk5 phase currents, and Brk4 phase currents. At two milliseconds, the prototype sends the Brk5 action signal.



# 2. Conclusion

The goal of this study is to prevent short circuit failures in the shipboard power system. A sophisticated defense mechanism is created for the shipboard distribution network. The protection system uses a BP neural network to map faults to strategies based on the breaker switching mechanism. The maximum three-phase current (rms) of each breaker is fed into the neural network. The intelligent protection prototype has been tested and simulations under various circumstances have been run. The outcomes show that the protection system satisfies the requirements of speed and selectivity and can accurately detect all errors in 7 ms.

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# 46. Diagnosis of power system protection issues

A few factors of power system transformation

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#### Abstract

There are several difficulties facing the infrastructure that supplies electricity. The difficulties that the future development of European power systems will face are determined by the current patterns. It was done so as to identify these problems. Various viewpoints of the power system as a point of reference were assumed in the analysis. Along with technological factors, the investigation took into account formal and legal considerations, social expectations, economic challenges, security requirements, energy independence, and other issues. This simplified the process of determining the essential elements. They might alter the way power grids operate. The article's main objective is to outline the necessary elements needed to alter the current paradigm for power system protection.

Keywords: power system protection, power system development, energy communities, electromobility, energy stores

## 1. Introduction

Power system protection (PSP) is necessary for the power system (PS) to operate in a safe and dependable manner. The PSP plays a critical part in the PS. Protecting PS objects and users against the impacts of aberrant operating conditions is one of the PSP's responsibilities [1]. This is a challenging assignment to accomplish. It is vital to guarantee that the disturbance is promptly detected and that the impacted object is turned off as soon as feasible. This is necessary to lessen the risk to this object, other nearby objects, and the possibility that the disturbance will spread to other areas of PS [2].

Thus far, the PSP's functionality and configuration have been carefully chosen for every object, keeping in mind the particular PS operating conditions anticipated at the point of connection for that particular object in the PS. Years of experience have shaped the information that is employed, and the European PS's effective use of PSP is surely proof that this method is accurate. Nonetheless, there are some difficulties facing the European power system. These difficulties are a result of the PS operation model modification. It was done to identify these difficulties. They might alter PSs' operational model.

The article focuses on characterizing the most significant variables that have been found to be those that need to modify the way PSP is currently approached. As these solutions have previously been tried and tested in the past, this may in many cases require their abandonment or substantial modification. However, before making any changes to the current solutions, a comprehensive examination should be conducted. Their use has made sure that PSs operate safely and dependably and that all parties involved in the energy market consume electricity safely. Nonetheless, the noted modifications in PSs' operational architecture could mean that the current fixes prove inadequate or even hazardous. It is unquestionably quite challenging. This is because of the significant function that the PSP plays in the power system.

# 2. Common Energy Market in the European Union

The European Union's (EU) initiatives to strengthen economic coherence in the PS are what drive the single energy market issue [3]. These initiatives are carried out with the assistance of so-called network codes (NCs). The NCs are a series of regulations that are implemented in accordance with EU law to create a unified electricity market.

II. The NCs have the upper hand over national laws and frequently have the power to rewrite the rules for utilizing and overseeing PS operations. This results from a shift in how each EU nation's PSs are viewed inside the EU energy market (Figure 1).



National energy markets

Common energy market

**Figure 1.** Change of the model of PSs in the EU after the introduction of NCs

Requirements that should guarantee a consistent PS operation throughout EU member states in the common energy market are developed in the NCs. To facilitate electricity trading within the EU and guarantee PS security, the NCs establish uniform promote the integration of renewable energy sources (RES), boost competition, and enable PSs to use their resources more effectively, all of which should benefit electricity users overall. The NCs also include specifications for PSP's settings and functioning [4].

Because the NCs are more powerful than national laws, they provide a significant issue. It is imperative that the system operators (SO) consider this. They have a lot of trouble coming up with precise needs because of this. While historical needs, which are frequently different in different countries, should be taken into consideration, the EU's goal of unifying the operation of separate PSs within the EU common energy market should also be taken into mind. To guarantee the continued safe and dependable operation of all PSs in the EU, such an approach is required. As a result, the process for developing PSP requirements alters as a result of the adoption of NCs. A new method is depicted in Figure 2.



Fig. 2: Change of approach to the formulation of requirements for PSP

Regardless of the EU member state participating in the single energy market, PSP responds to an abnormal state of operation. This is an opportunity for SO, particularly for the transmission system operator, since it will facilitate the agreements amongst system operators about the PSP for cross-border connections and nearby objects. Furthermore, it will make it possible for SOs in any EU nation to share experiences with new PS disruptions more quickly.

Standardizing the minimal technological specifications for PSP and collaborating devices (measurement instrument, communication, etc.) will be made possible by the deployment of NCs. For SOs, it is a major opportunity, as it is anticipated that this will eventually result in PSP unification within the EU common energy market. It will make high-quality products more easily accessible (because PSP manufacturers are likely to concentrate on producing a single kind of equipment for the common market).

# 3. Energy Communities, Renewable Energy Sources

The issue posed by the obvious trend towards implementing PS reform in the area of energy democracy, i.e. taking societal expectations into account, is energy communities and renewable energy sources. Energy clusters, energy cooperatives, and other energy communities (EC) are developed as a result of it [7-9], and [10]

In [4], the expected impacts of NCs introduction in the Polish PS are evaluated. The NCs data from the connection area, which contained the majority of the PSP requirements, were carefully examined. The requirements that were established were contrasted with the current national PSP approach. It was made very evident that the method used to determine PSP's settings and operation did not need to alter. This is crucial because it has long been established that the current practice is correct, and the PSP requirements have been established based on years of national knowledge and experience, adhering to international and national standards.

However, the arrival of NCs also presents SO with entirely new difficulties. New dangers to PS that need to be mitigated by PSP are displayed in NCs. Subsynchronous oscillations will be one such difficulty for the Polish PS ([5] and [6]). Since these disruptions have not yet been noticed on the Polish PS, there isn't a specific PSP.

In addition, the implementation of NCs and the standardization of the PSP methodology across the pan-European PS ought to yield results that are same to or comparable to the anticipated network. As a result, connections between the EC network and the remainder of the PS could occasionally be empty or only partially loaded. This is going to occur when the European Community's supply and demand for power are balanced. This is the absence of load or low load on the EC-PS connection could lead to issues with the PSP of this connection. Because processing such signals might result in significant mistakes when computing the criteria values in digital PSPs, some protection functions are inactive at low current values (10% of the measuring apparatus's rated secondary current is typically regarded as a threshold for the protective functions' activity). It is risky since it will take longer to unhook the object in the event of a short circuit. The protection function must first be activated (this will happen automatically because the short-circuit will increase the value of



**Figure 3.** Power exchange between EC and PS for imbalance (a) and balance (b) of energy within EC

the current). The PSP will then check the object's operating conditions, detect the short-circuit, and elaborate on the decision to disconnect the object. This is a problem for PSP since it necessitates the adoption of new protection features that must operate at low current levels. Typically, LV and HV networks employ these protection functions rather than MV and LV networks.

For EC, there was also a possibility of unnoticed island operation of an EC network. This relates to the scenario where the supply and demand in the EC are balanced by cutting off the link between the PS and the EC network. At the moment, MV and LV networks lack a PSP that would enable the detection of such circumstances. This increases the likelihood that such an EC network will operate. It is seen in Figure 4.



**Figure 4.** No detection of non-intentional island operation of EC in thesituation of switching off the connection between EC and PS

The amount of short-circuit power in the EC network will be much decreased during EC island operation, which could lead to a reduction in the effectiveness of the electric shock protection and a failure to provide the necessary PSP reaction to short circuits in the EC. It is necessary to take these risky scenarios into account while choosing the PSP's functionality and settings in the EC. Because it is impossible to forecast where EC will be developed, SO faces a great deal of challenge. These are usually grassroots endeavors. Therefore, almost every component of MV and LV networks could eventually be owned by EC. It suggests that when analyzing the accuracy of PSP operation and outfitting, the EC island operation must be taken into consideration.

Without a doubt, the advancement of EC will aid in the continued rapid expansion of RES. Furthermore, this would reaffirm the issue that PSP has already faced, which calls for a revision of the fundamental premise that was previously accepted when choosing PSP's functionalities and settings. These days, it is almost universally believed that current flow with high-current metallic short-circuits a number that is more than PS's long-term allowable current limit. The stable short-circuit current, however, might not even be greater than the rated current for a large number of RES ([16] and [17]). It will complicate the identification of short circuits (see, for example, to [17]). Nevertheless, NCs impose the need that the majority of newly installed RES be outfitted with quick short-circuit current injection systems, which ought to at least

Ensuring safe working conditions for maintenance services is also a crucial requirement. When there are a lot of RES in the PS, it can get problematic. It was frequently the case that even after a PS part was disconnected, RES continued to function, which prevented a voltage-free state from being achieved in such a network. Furthermore, there is a chance that RES that have been switched off could eventually turn on automatically (because to better wind or sun conditions, for instance) and begin generating power for the network where the work is being done. The aforementioned circumstances ought to be disregarded, and this should be considered while drafting the PSP requirements.

There is indication that the current method of implementing system services (such frequency regulation and voltage regulation in MV and LV networks) may need to be changed due to the expected withdrawal of large-scale power sources. Currently, large-scale sources are typically used to regulate frequency. But their slow departure will mean that, among other things, RES will need to be involved ([18] and [19]). NCs also aim to achieve this. Because of the proliferation of RES and EC, PSP is facing yet another obstacle. In order to avoid prematurely shutting down the RES (for example, by setting the protection against island operation too restrictively [20]), it should be considered when choosing the functionality and settings of PSP

#### 4. Electromobility

A new class of electricity users has emerged, posing challenges to electromobility. Because their usage of PSs is still unstandardized, it is challenging to prepare PSs for the anticipated widespread purchase of electric vehicles.

Many consumers, concerned about their comfort, anticipate that charging stations, which are sometimes tucked away in PS, will receive a steady supply of electricity. It can result in PS operating under poor circumstances, where some items will be overwhelmed. These circumstances will arise more frequently the more charging stations there are and the more electric vehicle users utilize them concurrently. Then, widespread adoption of safeguards against the impacts of overloading deep in MV may be necessary to minimize the danger of harm to PS objects.

As well as LV networks. From a long-term standpoint, it appears that it will be inevitable. Furthermore, a high rate of station connections will be required because to the anticipated rapid proliferation of electric vehicles, frequently at PS locations that are not already equipped for this use. Consequently, it is advised that PS have a charging station.

creating the specifications for PSP, or at the very least, choosing the features of the PSP that will be implemented in PS. This will enable connecting a charging station without the need to replace the PSP. The availability of vehicle-to-grid (V2G) systems, which enable bi-directional energy transmission between PS and electric car (see [21] and [22]), should also be taken into account. Potential energy exchange between an electric vehicle and PS is depicted in Figure 5. This is an additional electromobility-related factor that PSP needs to consider.



Figure 5. Idea of V2G

#### 4.1 ENERGY STORAGE

The problem of energy storage is dictated by the advent of policies that permit a drastic shift in the way electricity is controlled and do away with the traditional paradigm. Widespread energy storages are assumed in the new PS model. As a result, producing power in a quantity appropriate for the present demand might not be necessary.

There are no comprehensive laws specifically pertaining to energy storage systems in the European PSs. As a result, the current method treats them as either generating sources (for the case of energy introduction into PS) or loads (for the case of energy consumption from PS). The energy capacity of energy storage devices, which establishes the amount of energy that can be stored, as well as the non-identity of the features of various energy storage technologies, which establish, among other things, the maximum value of PS output/input power and temporal availability, should be taken into consideration when evaluating the effects of energy storages on PS [23] and [24].

To show their potential influence on PSP, the energy storages' specified characteristics must be identified. High-capacity storages are typically connected to HV and LV networks, according to basic analyses, which allows for the conclusion that there won't be any appreciable changes to PSP's working circumstances. However, MV and LV networks might undergo modifications. In addition to RES, energy storages will now be objects, which might lead to an increase in the frequency of changes in the directions of energy flow in these networks. When choosing the features and configurations of PSP, this should be considered (for example, by applying directional protections.

PSP selectivity, or to turn off storage that is in the charging mode when there is a PS frequency drop. The possibility of prosumers connecting energy storages was also considered when assessing how energy storages affected PS and PSP functionality. According to what is mentioned, an electric vehicle that is compatible with V2G will likely be the most typical situation at first. Technology is a potential energy source [21]. In certain cases, the prosumer installation may "transfer" to island mode operating without any issues in such a circumstance. Subsequently, there will be a considerable decrease in the short-circuit power in this installation, which could result in the prosumer installation's PSP not operating as needed and a reduction in the efficacy of the electric shock protection. When choosing the features and configurations of PSP meant for use in prosumer installations, they must take the prevention of such hazardous scenarios into account.

In order to employ the energy storage capacity to deliver system services, consideration must also be given to the requirement of guaranteeing access to the electrical grid even in the event of interruptions. Among their many uses are as a source of synthetic inertia [23], enhancer of the electrical quality parameters, stabiliser of the stochastic RES profile, emergency supply in case of calamity, etc. When choosing PSP functionalities and settings, they must take into account ensuring the proper execution of these activities. It is difficult because it necessitates being receptive to concepts being defined or to solutions that are now in prototype.

# 5. Conclusions

The study presents the problem analysis of the challenge for PSP, the estimation of potential problems, the source of change, and the anticipated influence on the operation of European PSs for a few chosen challenges. Based on the conducted analysis, it can be concluded that major issues with ensuring PSP operates correctly may arise in the near future if no attempt is made to identify, develop, and implement new solutions for PSP at the beginning of the identified changes in PSs or on the eve of their occurrence. The dramatic shifts in "network existence" demand this. The paper, which highlights some of the PS transformation's issues for PSP, is intended to help the authors quickly build multivariate solutions that mitigate those challenges.

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# 47. Comprehensive investigation of the architectures of single-stage switched-boost inverters

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#### Abstract

In energy from renewable sources systems (RES), single-stage switching boost inverters (SBIs) with buck-boost capabilities are widely used. The goal of this study is to provide an extensive topological analysis of several single-stage SBI circuits. SBI uses switched-inductor, switched-capacitor, and transformer-assisted switches as boosting strategies. Depending on the uses, each SBI-derived structure offers advantages and disadvantages of its own. Additionally included is the performance evaluation of SBIs from a variety of angles, including boost factor, voltage stress across active devices, number of passive parts, DC link voltage, switching losses, voltage gain, and efficiency. In one stage SBI, the required boosted and inverted ac output voltage is obtained by using an appropriate modulation approach. Finally, a section on various modulation schemes used for SBIs is included in the topological overview. The contribution of this topological review helps researchers choose optimal SBI with efficient modulation algorithms that are acceptable for applications using renewable energy. Additionally, a thorough discussion of each converters' advantages and disadvantages is provided.

Keywords: Boost Inverters (BIs), control approaches, grid synchronization and single-stage inverter.

## 1. Introduction

As energy demand rises, renewable energy sources (RES) are gaining popularity [1–3]. Various strategies have been used to use renewable energy. Renewable energy sources include sun, wind, tides, waves, and geothermal heat [4]. Solar PV, plentiful in nature and low-maintenance, is a top recommended solution [5]. Grid-connected solar systems consist of solar panels, inverter, power conditioner, and grid connection equipment [6]. Grid-connected systems range from rooftop business models to large-scale utility grid power platforms. The power conversion system might be single- or two-stage. A nano-grid is a lowpower system with two-stage power conversion, ideal for domestic use. For a two-stage nanogrid system [7-10], a solar panel, DC/DC converter, VSI, and storage unit with a bidirectional converter are needed.

VSI is essential to PV power conversion. The efficient conventional VSI is frequently utilized in industry for distributed power systems. Traditional VSI has serious difficulties. The alternating voltage is lower than the DC source voltage. The VSI faces challenges like dead time, insecurity against shoot-through, and EMI [11]. Shorting of inverter legs due to EMI might harm the switches. Additionally, the two-stage conversion mechanism is complicated, making the control circuit more challenging. The z-source inverter (ZSI) was created in 2002 to overcome the complexity of the two-stage construction [11]. A thorough examination of Z source and switched Z-source network topologies is available in [12].

Small signal analysis is undertaken for structures having a simple switched Z source network, and the overall signal flow graph is shown in [12]. ZSI, unlike standard VSI, may raise or buck DC input voltage via a shoot-through condition. Thus, the inverted voltage may differ from the DC source voltage. Also, ZSI has strong EMI and noise protection capabilities, enhancing system dependability. The ZSI architecture is promise for RES-based distributed generation, including fuel cells, solar, wind, electric hybrid cars, UPS, and induction motor drives [13-21]. Various ZSI topologies, including qZSI, SL-ZSI, Trans-ZSI, T-ZSI, SC-ZSI, and multilevel ZSIs, are studied in the literature [32, 33].

Adding passive parts (inductors and capacitors) to ZSI and its topologies increases the weight and cost of the power converter system (34). In low-power applications, ZSI is not preferred due to size, weight, and cost constraints. Additionally, the impedance network requires symmetrical passive parts. Or, it may cause complicated right-hand pole-zero pairings during low-frequency operation [34].



Switched Boost Network H-Bridge

Figure 1: Topology of Boost switched inverter [35].

We propose a switched boost inverter (SBI) [35] to replace ZSI in DC nano-grids, reducing component count and complexity. Figure 1 depicts a main SBI circuit, considered an appealing topology to circumvent ZSI restrictions. The original SBI [35] uses the Inverse Watkins– Johnson (IWJ) architecture [36], reducing the number of passive components in ZSI.

See [35] for the working concept and steadystate waveforms of basic SBI. It offers the benefits of ZSI without the need for separate boost stage control.

SBI allows shoot-through, much like ZSI, eliminating the need for a dead-time protection circuit, resulting in a small system. SBI offers EMI noise protection and a diverse output voltage range [10]. This circuit functions as a DC/DC boost converter in standalone systems before being connected to an inverter to supply both DC and AC electricity. Basic SBI for high boost applications shows high stress across the capacitor. The source side's current profile is discontinuous due to the DC source (Vin) series connection with a diode (D). In different SBI topologies, traditional and customized SBC approaches are applied to produce greater boosts and attain shoot-through states [35]. Improving SBI using topologies such enhanced SBI, CFSI, quasi SBI, and trans-SBI has been suggested in the literature to address its faults [37-41].

This review study is crucial for identifying classifications of switching boost network-based inverters for boosted DC-to-AC power conversion.

In this article, important SBI-derived topologies are surveyed and characterized. This article examines alternate SBI architectures and analyzes their performance along with factors such as boost factor, voltage stress across active devices, DC link voltage, switching losses, voltage gain, and efficiency. The study compares component count, boost factor, voltage gain, and stress on capacitors and switches for each topology to aid researchers in choosing an appropriate switched boost network for various applications. PWM techniques must be used to modify SBI topologies for increased boost. Several PWM approaches are available in the literature to accomplish this. Modulation methods used for ZSI may be used to any SBI topologies [46-51].



Figure 2: Basic single-phase alternative SBI structure categorization

This study focuses only on switching boost inverters and their related topologies. Considerations for evaluating SBI performance include boost factor, voltage stress across active devices, passive element count, DC link voltage, switching losses, voltage gain, power rating, and efficiency. Presenting design factors for studied SBI topologies helps potential researchers comprehend them. A thorough evaluation of PWM techniques for SBI is crucial for matching the switching boost network to the application needs. Therefore, it is placed at the conclusion of the review piece.

Continued portions of this article follow this structure: The fundamental categorization of single-stage SBI topologies is covered in Section 2. SBI topologies are compared for performance in Section 3, and modulation approaches for SBI variations are discussed in Section 4. Section 5 presents experimental findings of fundamental SBI structures to improve understanding of SBI circuit performance. Lastly, Section 6 covers the review's scope and conclusion.

# 2. Topologies Derived from Switched Boost Inverters

Figure 2 depicts the major categories of single-phase SBIs. Figure 2 illustrates four primary forms of SBI: single-phase alternative, quasi switched boost inverter (qSBI), multilevel qSBI, and three-phase SBI. The basic SBI voltage boost network is enhanced by incorporating transformers (Trans-SBI) [41], switched inductors (SLBI) [42], and switched capacitors (SCqSBI) [43] in literature. This article classifies the modified structures as single-phase alternative SBI structures. Figure 3 categorizes single-phase alternative SBI topologies, resulting in better SBI, CFSI, trans-SBI, SLBI, and SBI with four switches [37-72]. Alternative structures are created by rearranging fundamental SBI components. Each SBI structure has pros and cons for certain purposes. Further details on these setups are provided in later sections.



Figure 3: Single-phase alternative SBI structure classification



Figure 4: Improved topology of SBI [37]

#### 2.1 Alternative Single-Phase SBI Architectures

Figure 3 depicts the categorization of singlephase alternative SBI structures, which begin with a better topology [37].

#### 2.1.1 Improved Topology of SBI [37]

Figure 4 illustrates the better topology suggested in [37]. The component count is the same as simple SBI, but the capacitor experiences the lowest voltage stress. The voltage stress across the switch (S) in both basic and upgraded SBI stays constant. The stress across the diode is same for both basic and modified SBI topologies. It is mostly used in nano-grid applications.



Figure 5: Current fed switched inverter (CFSI) [38]

As rice is the sole food crop cultivable in tropical regions during monsoon season, Asia holds the global lead in rice production. Disposing of rice husks poses a significant challenge, leading to the construction of larger mills. Throughout the growth period, the protective coating of rice

#### 2.1.2 Current Fed Switched Inverter (CFSI) [38]

The CFSI [38] has a high voltage gain characteristic that is equal to ZSI, but requires less passive parts compared to SBI. The CFSI topology is derived from the current-fed DC/DC topology. Figure 5 displays the diagram of the CFSI structure. This suggested CFSI aims to attain high tolerance to EMI noise and is well-suited for harnessing renewable energy due to its continuous source current. The SBC technique-II, as described in Table 1, is used to generate the switching pulses [38].

#### 2.1.3 Trans-Switched Boost Inverters (Trans-SBI) [41]

A two-winding transformer replaces the inductor in SBI, creating the Trans-SBI topology [41]. Changing the turns ratio results in a larger voltage increase and gain. A transformer-based SBI family is presented in literature [41] for fuel cell and PV applications. Benefits of trans-SBI include reduced size, weight, and cost, and enhanced efficiency. Although the Trans-SBI features an extra active switch, it significantly decreases the number of passive parts. The firing pulses are generated using the modified SBC technique-III in Table 2 [41].

#### 2.1.4 Switched-Inductor Boost Inverters (SLBIs) [42]

A series of SLBIs is introduced utilising the switched inductor (SL) approach for SBI topologies [42]. Type-1 and type-2 SLBIs have four separate voltage sources, as shown in Figures 6(a) and 6(b). Different topologies may be created by placing DC input sources with subscripts from 1 to 4 in various positions. For convenience,

Type-I and Type-II SLBIs are classified by input supply voltage position as DC-linked, discontinuous, ripple, or continuous. The SLBI is smaller and cheaper than regular SBI, resulting in improved efficiency. It excels in fuel cell and solar cell applications because to its strong boost factor. The firing pulses are generated using the modified SBC technique-IV in Table 3 [42].



**Figure 6:** SLBI topologies [42], (a) SLBI topology of Type-1, (b) SLBI topology of Type-2

	#	##	###	*	* *	* * *	\$	\$\$	\$\$\$	@	@@	@@@	#*	*\$	\$@	#*\$
Switches	5	4	5	5	5	6	5	5	5	5	5	5	5	4	4	14
Diodes*	5	5	6	6	6	6	6	6	9	9	9	9	8	6	6	16

Table 1: Types of Topologies

#: boosted VSI, ##: ZSI [11], ###: SBI [35], \*: Embedded type qSBI [39], \*\*: DC linked type qSBI [39], \*\*\*: MSBI [45], \$: Trans SBI [41], \$\$: CFSI [38], \$\$\$: Discontinuous SLBI [42], @:

DC linked SLBI [42], @@: cSLBI [42], @@@: rSLBI [42], #\*: SC-qSBI (2 cell) [43], \*\$: HB-qSBI [71], \$@: HB-SBI with four switches [73], #\*\$: 3LT<sup>2</sup>qSBI [44].

	#	##	###	*	* *	* * *	\$	\$\$	\$\$\$	@	@@	@@@	#*	*\$	\$@	#*\$
Switches	5	4	5	5	5	6	5	5	5	5	5	5	5	4	4	14
Diodes*	5	5	6	6	6	6	6	6	9	9	9	9	8	6	6	16

 Table 2: Types of Switching topologies

#: boosted VSI, ##: ZSI [11], ###: SBI [35], \*: Embedded type qSBI [39], \*\*: DC linked type qSBI [39], \*\*\*: MSBI [45], \$: Trans SBI [41], \$\$: CFSI [38], \$\$: Discontinuous SLBI [42], @:

DC linked SLBI [42], @@: cSLBI [42], @@@: rSLBI [42], #\*: SC-qSBI (2 cell) [43], \*\$: HB-qSBI [71], \$@: HB-SBI with four switches [73], #\*\$: 3LT<sup>2</sup>qSBI [44].

Topology	Swaitches In boost network	Switch in inverter bridge
SBI [35]	D Vin	<u>1-D</u> V:-
Embedded type qSBI[39]	$\frac{1-2D}{1}V$	$\frac{1-2D}{1}V$
SLBI[42]	$\frac{1-2D}{1+D}V$	$\frac{1-2D}{1+D}$ V
CFSI[38]	$1-3D^{\vee in}$ 1	$\frac{1-3D}{1}$
SC-qSBI[43]	$1-2D^{V in}$ $\frac{1}{1}$	$\frac{1-2D}{1}V$ in $\frac{1}{1}V$
HB-qSBI[70]	$\frac{1-2D}{1-D}V_{in} \frac{D}{D}V_{i}$	1-2 <i>D<sup>V in</sup></i>
	$ \begin{array}{ccc} 1-3D & {}^{t} & {}^{tn} & 1-3D & {}^{tn} \\ for S & 1 & for S & p \end{array} $	NA
		_ <u>1</u> -D

Table 3: Different Switching Network



Figure 7: Topology of Modified SBI [45]

#### 2.1.5 Topology of Modified SBI (MSBI) [45]

The suggested MSBI architecture [45] offers higher voltage gain than basic SBI and ZSI. Refer to Figure 7. This inverter has two switched boost networks, enhancing its boost factor. It produces three voltage output levels. This modified design includes one DC voltage source (Vin), four switches S1-S4, and two diodes D1-D2 in addition to normal SBI components. S1 and S2 input switches significantly enhance the inverter's voltage gain compared to the basic SBI. The input side switches (S1 and S2) are disabled by soft switching (ZVS). The switches (S1 and S2) have low voltage stress equivalent to the input voltage, reducing system cost Figure 8. Additionally, it reduces conduction and switching losses [45]. This enhances efficiency and dependability.



Figure 8: SBI topologies [71], (a) Topology of Half Bridge based SBI, (b) Topology of Full Brdige based SBI

#### 2.1.6 Topologies of Full-Bridge (FB) and Half-Bridge (HB) of SBI

The suggested MSBI architecture [45] offers higher voltage gain than basic SBI and ZSI. Refer to Figure 7. This inverter has two switched boost networks, enhancing its boost factor. It produces three voltage output levels. This modified design includes one DC voltage source (Vin), four switches S1-S4, and two diodes D1-D2 in addition to normal SBI components. S1 and S2 input switches significantly enhance the inverter's voltage gain compared to the basic SBI. The input side switches (S1 and S2) are disabled by soft switching (ZVS). The switches (S1

and S2) have low voltage stress equivalent to the input voltage, reducing system cost. Additionally, it reduces conduction and switching losses [45]. This enhances efficiency and dependability.

#### 2.1.7 Inverter Power Decoupling Current Source

Single-phase micro inverters (SMIs) inject intermittent electricity to the grid, causing voltage fluctuations at the point of common coupling (PCC). Additionally, the power disparity between SMIs' DC and AC terminals causes double-line frequency pulsing power at the DC terminal, boosting component ratings. Figure 9 illustrates the power-decoupled current source inverter (PD-CSI) developed in [98] to alleviate SMI difficulties. The PD-CSI delivers reactive power compensation for PCC voltage regulation. Meanwhile, an active power decoupling circuit is included. The device stores double-line-frequency power in a film capacitor, enabling continuous DC current for PV operation. Additionally, the PD-CSI provides reactive power adjustment and efficient conversion with fewer switches. Hence, the PD-CSI interface is cost-effective for low-power applications.



Figure 9: PD-CSI Circuit Diagram

#### 2.1.8 Four Switches Configuaration of Single-Phase SBI

In [72], a single-phase SBI with four switches utilizes qSBI advantages including better input profile and buck-boost voltage capability to provide shoot-through immunity. The single-phase SBI with four switches (S1-S4) is shown in Figure 10. Compared to qSBI topologies, this architecture has fewer power switches and incorporates an extra capacitor Unlike CSI, this architecture is shielded against open circuits [72]. Open circuit situation causes current to freewheel via diodes (Da and Db) in Figure 10, without causing spikes on circuit components. In conclusion, the topology is extremely dependable. Inverter inductance, power ratings, and voltage gain need are lower than qSBI. MSBI requires a larger capacitance than qSBI [39]. A low-frequency current ripple occurs in the input current. Capacitor voltage stress exceeds qZSI [22] and matches qSBI. The switch and diode stress resembles qZSI/qSBI topologies. However, the converter cannot improve boost beyond qSBI.



Figure 10: Four Switches Configuaration of Single-Phase SBI



Figure 11 Topologies of Class of qSBI

#### 2.2 Quasi SBI and its Derivative Topologies

The circuits that are formed from a family of quasi-SBIs (qSBIs) are shown in Figure 11. Increased boost factor, less capacitor stress, and an enhanced source current profile are just a few of the advantages that qSBI has over traditional SBI. In Figure 11, we can see that the fundamental qSBI circuits may be divided into two types: embedded and DC connected. Microgrids powered by photovoltaics and fuel cells work particularly well with the suggested qSBI topologies.There is a detailed comparison of the qSBI and qZSI topologies, which both have a single phase [40].

The parts that follow will go over the various qSBI structures that are shown in Figure 11.

# 2.2.1 Structures of the Embedded qSBI Kind [39]

Longer embedded type qSBI uses the same number of components as basic SBI. Continuous source current is generated using an increased voltage enhancement on the DC bus. Both the input source and inverter bridge share ground. The embedded variant of qSBI is often used in high-power systems.

#### 2.2.2 Topologies for DC-Linked qSBI Types

One major benefit of DC connected type qSBI is that it reduces stress on the capacitors. As described in [39], DC connected qSBI involves connecting the DC source to the switching boost network or the inverter's positive or negative DC bus. If you aren't very concerned with enhanced voltage gain, the DC connected type qSBI is a solid pick. The qSBI topology class is tailored to use the modified SBC technique-III, which is described in Table 4 [39]. Figure 12 shows a half-bridge qSBI that has just been introduced; this section explains it. It has decreased capacitor stress.

# 2.2.3 Design for qSBI with a Half-Bridge (HB) [70]

The lack of impedance source network and inrush current in HB-qSBI leads to improved voltage gain performance. Eliminates shootthrough issues and boosts voltage gain. The modest capacitance of HB-qSBI reduces weight and cost. The updated technique-VI generates switching pulses for HB-qSBI topology.

#### 2.2.4 "SC-qSBI" Stands for "quasi-Switched Boost Inverters" and is Based on Switched Capacitors [43]

To increase voltage gain, consider using a switching capacitor [43]. The switched-capacitor approach is often employed in DC/DC converters [52, 53] and DC/AC power inverters [54, 55]. To create single-phase SC-qSBIs, connect an extra capacitor (C0) and diode (D3) to the qSBI, as illustrated in Figures 13(a,b). The SC-qSBI boost network consists of two capacitors (C0 and C1), diodes (D1-D3), an active switch (S0), and an inductor (L1). Two kinds of SC-qSBI setups exist: type-I and type-II. These inverters may be upgraded to n-cells to enhance voltage gain [43]. SC-qSBI topologies provide decreased capacitor stress, minimal stress between switch S0 and diodes, low shootthrough current stress, high voltage gain, continuous source current profile, and shoot-through immunity. Table 5

Table	4: (	Overview	of	different	modu	lation	techniques
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Modulation techniques with reference paper	Topology	Features
Conventional SBC tech- nique [35] Modified SBC tech- nique –I [35]	Basic SBI	<ul> <li>There are four shoot-through states in each switching time period T<sub>s</sub> and maximum modulation index M is equal to 1.</li> <li>This technique provides two switching cycles per switching period (T<sub>s</sub>).</li> <li>Switching frequency remains always constant.</li> </ul>
Modified SBC technique -II[38]	CFSI	- The modified PWM scheme-II is based on the traditional sine-triangle PWM with unipolar voltage switching.
Modified SBC tech- nique –III [39,41,43]	Family of qSBI & Trans-SBI & SC-qSBI	<ul> <li>The modulation index during the shoot-through state is kept as (1 – M) which is maximum.</li> <li>The shoot-through state is inserted into the traditional zero states only and hence the addition of shoot-through duty ratio and the modulation index is less than 1.</li> <li>Here only the negative shoot-through envelop is used.</li> </ul>
Modified SBC tech- nique –IV [42]	SLBI	<ul> <li>The maximum shoot-through period is (1 –M) and the shoot-through state is only inserted into the traditional zero states.</li> <li>Positive shoot-through voltage is used.</li> </ul>
Improved SBC tech- nique-V [72]	Single-Phase qSBI with Four Switches	- A triangular carrier signal $(V_{tri})$ with frequency $f$ and magnitudes of 1 and 0 pu is used. To determine shoot-through state, two constant signals $V_{sT}$ and $V_{sT2}$ are applied.

Modulation techniques with reference paper	Topology	Features
Modified SBC technique–VI [70]	HB-qSBI	-In this technique, triangular carrier is compared with two constant signals to determine shoot-through duty cycle [70].
		The maximum and minimum values of carrier signals are 1 and 0.
Modified SBC technique -VII[44]	3L qSBT <sup>2</sup> I	-High-frequency inductor current ripple is half compared to convention- al method SBC technique
Modified SBC technique –VIII[72]	HB and FB- SBI topologies	-The relation between shoot-through duty cycle and two control voltages used in this technique is $V_P = -Vn = 1 - D_{ST}$ . $V_{ST1} = D_{ST}$ and $V_{ST2} = 1 - D_{ST}Vp$ , $-Vn$ are positive and negative reference voltages. $V_{ST1}$ , $V_{ST2}$ are the shot through voltages and $D_{ST}$ is the duty ratio
Phase shifted PWM [87]	Single phase CF-qS- BI & Single phase SC-CFqSBI	-It offers output voltage with less harmonic content.
Improved PWM technique [94]	qSBI structures	-Improves the modulation index

Table 5: Brief about Modulation Techniques

describes the improved SBC technique-III [43] utilized to generate inverter firing pulses.



Figure 12: Design for qSBI with a Half-Bridge (HB) [70]



Figure 13: "SC-qSBI" stands for "quasi-switched boost inverters" and is based on switched capacitors [43]

#### 2.2.5 T-type Inverter with Three Levels Of Quasi-Switched Boost (3L qSBT2I) [44]

Figure 14 shows the three-level inverter configuration that combines the qSBI network with a three-level T type circuit architecture. The inverter is characterized by its lowest modulation index, high voltage gain, and low inductor current ripple. By regulating the duty cycle of two separate devices, the 3LqSBT2I is able to achieve a larger voltage gain [44]. Notable benefits of this inverter design include a high modulation index, little ripple in the inductor current, and increased voltage gain [44]. Medium and low power distributed generation may make advantage of this design.

# 1.3 Topologies for Single-Phase Multilevel SBIs

Multilevel inverter (MLI) topologies are often employed in high power and medium voltage applications [56-69]. It provides high-quality output voltage, decreased stress, EMI, and switching losses [73-75]. The major types of MLIs include cascaded H bridge inverters (CHB) [76-78], neutral point clamped inverters (NPC) [79-80], and flying capacitor (FC) inverters [81]. Traditional MLIs have drawbacks including more switching components and complex driving circuits. Thus, the MLIbased system becomes more complicated and less trustworthy. Researchers recently studied Z source-based MLIs for single-stage buck and boost [82-85]. To simplify Z source-based MLIs, SBI-based multilevel converters are suggested [86-87, 97, 99].

#### 2.3.1 The CF-qSBI is a Solitary-Phase Cascaded Five-Level Quasi-Switched Boost Inverter

A five-level cascaded qSBI is shown in [86, 87] for grid-connected applications. The CF-qSBI has two SBI modules with separate DC sources and an inductor filter (Lf) at the inverter terminal. Figure 15 illustrates the output voltage qSBI, which is a consequence of two modules and a single-phase cascaded five-level qSBI. The cascaded approach solves the imbalanced DC-link voltage (VPN) issue, a major concern with traditional CHB inverters. The DC-link voltage is controlled by the capacitor voltage (Vca) under dynamic source and load situations. The cascaded five-level qSBI works for both static and dynamic supply voltages. This inverter architecture addresses short circuits and dead time in H-bridge circuits.

2.3.2 Capacitor-Structured Single-Phase Cascaded Five-LevelQuasi-SwitchedBoostInverter (SC-CFqSBI) [97]

The single-phase CFqSBI topology is suggested in [97]. Two identical modules are cascaded and powered by two independent DC sources. The circuit architecture and operating concept of SC-CFqSBI are described in [97]. Control signals are generated using a modified PS-PWM algorithm [87]. The inverter provides enhanced voltage boost and gain with a minimal duty ratio. Higher efficiency is achieved with lower voltage stress compared to traditional MLI and five-level qSBI systems. The following section briefly discusses three-phase SBI in the literature.



Figure 14: T-type inverter with three levels of quasiswitched boost (3L qSBT2I) [44]



Figure 15: The CF-qSBI is a solitary-phase cascaded five-level quasi-switched boost inverter

#### 2.4 SBI Topologies of Three-phase

Three-phase switching boost structure-based SBI topologies are presented for high-power applications [88]. The categorization of three-phase SBI topologies is shown in Figure 16. It consists of three phases: conventional SBI and upgraded SL-qSBI.

# 2.4.1 Traditional Three-phase SBI Architecture [88]

Figure 17 depicts the three-phase conventional SBI topology that is explained in [88]. In [88], the operation, steady-state analysis, and its characteristics are described in detail. The standard SBC approach outlined in [35] may



Figure 16: Categorization of three-phase SBI architectures



Figure 17: Topology for standard three-phase SBI [88]



Figure 18: Stratifications with Three Phases! (a) The topology of three-phase SLBI [88] (b) cSL-qSBI topology in three phases [89]

also be modified to accommodate a three-phase SBI design.

SBI Technology with Current Ripple 2.4.2 Switched of Three-phase Input Current Ripple [89]

To decrease input current ripple in switched inductor qSBI (cSLqSBI), the basic SLBI inverter provided in [88] is enhanced, as illustrated in Figure 18(a). To modify the basic SLBI topology, move the input source in series with one of the inductors (L2), as illustrated in Figure 18(b). This significantly reduces input current ripple. It offers increased efficiency and power density. Another three-phase modified cSL-qSBI is addressed in [89].

#### 2.4.3 Topologies of Three-phase Cascaded Qsbi [90]

Figure 19 depicts a three-phase Cascaded H-Bridge qSBI (CHB-qSBI) suggested in [90]. The shoot-through duty ratio maintains consistent DC-link voltage levels for each inverter module. This eliminates the imbalanced DClink voltage problem in traditional inverters effortlessly. A multilayer qSBI may step up/down with the inversion.

#### 3. Present Problems and Potential Outline

Single-stage buck-boost inverters, including switching boost and derived architectures, have solved the drawbacks of traditional VSI and CSI. As an added benefit, SBIs may boost output voltage. The literature assessment indicates that single-stage boost inverters are more efficient, compact, and operable over a broad input voltage range. Single-stage boost inverters offer advantages, although businesses still rely on



Figure 19: A three-phase cascaded qSBI- topology [89, 90]

conventional voltage source inverters or step-up transformers. Therefore, pay greater attention to design concerns to fulfill industry standards and regulations.

Most topologies provide considerable voltage stress on boost network capacitors and switches owing to high DC bus voltage. In addition, low-frequency ripples in capacitor voltage and inductor current are undesirable for PV applications. Pay more attention to developing switching boost network components.

Utilize current feedback control approaches to reduce low-frequency oscillations in dc topologies for grid-connected applications.

Excessive shoot-through duty cycles for high voltage gain result in severe power losses in switches and diodes, reducing efficiency. Due to switching losses, most switched boost network topologies have lower efficiency. For high-power applications, switching boost networks must be synthesized and built to decrease power losses and maximize efficiency.

DC bus voltage spikes occur when linked devices are utilized with qSBI to boost voltage gain. Increased focus is required to generate PWM pulses for devices.

Practical implementations have EMI difficulties. Selecting the right switching frequency and shoot-through duty ratio for the input voltage helps minimize passive element size and address EMI concerns.

To extend gain and reduce switch voltage stress, add SL and SC cells. Using new power electronic technologies like GaN and SiC with high switching frequency, low loss, and high temperature capacity helps minimize the size of passive components. Furthermore, it enhances switching boost inverter topologies' efficiency, power density, and performance. Selection of switching frequency and shoot-through duty ratio based on input voltage may significantly minimize the size of passive components.

# 4. Conclusion

Using a switched boost network to circumvent the shortcomings of traditional two-stage boost inverters and ZSI topologies, the switched boost inverter is a cutting-edge power electronics converter topology that is rapidly gaining popularity. Its appealing features include boost characteristics and single stage conversion. Applications in nano-grids powered by photovoltaics work well with it. To increase the input voltage, a boost network switch is used to generate the shoot-through condition. Researchers are increasingly drawn to the flexible properties and various topologies of SBI.

This review article briefly discusses SBI and its variations, including qSBI, SLBI, T-type, Trans-SBI, half-bridge, full-bridge, and multilevel topologies. This study examines SBI classifications and topological improvements to maximize boost factor, reduce passive element count and size, minimize active device and capacitor voltage stress, improve input voltage utilization, and enhance EMI and reliability. An overview of SBI topologies in the literature is studied, focusing on boost factor and inversion efficiency. It also examines PWM techniques in different topologies to optimize switching processes and maximize voltage gain. This review paper helps researchers comprehend SBI topologies and their pros and cons. To maximize efficiency, choose an appropriate SBI structure based on the available dc source voltage and necessary ac voltage for the application.

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# 48. A practical approach to machine learning techniques in power system protection

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#### Abstract

In order to extend the useful lives of various components or instruments, the fourth industrial revolution has made it possible to collect massive amounts of operational data generated by a variety of Intelligent Electronic Devices (IEDs) and use that data in an automatic higher cognitive process, such as fault detection and diagnosis. The application potential of Machine Learning (ML) techniques in power system protection has been the subject of several research and scholarly papers in recent years, which has prompted power utilities worldwide to closely monitor developments in this field. The goal of this paper is to provide a utility perspective on machine learning approaches by outlining the limitations of different ML techniques and explaining why utilities and relays have not yet placed enough trust in ML.

Keywords: Machine Learning, Utility, Power system, Protection, Artificial Intelligence

# 1. Introduction

The fourth industrial revolution has enabled the collection of massive amounts of operational data generated by a variety of Intelligent Electronic Devices (IEDs) and their use in an automatic higher cognitive process, including fault detection and diagnosis (Dalstain & Kulicke 1995; Kezunovic & Rikalo 1996; Coury et al. 2002), with the goal of extending the useful lives of various components or instruments. Many authors have authored research and scientific publications in recent years on the application potential of Machine Learning (ML) techniques in power system protection, prompting power utilities all over the world to keep a close eye on advancements in this area. This study tries to offer a utility viewpoint on machine learning approaches, highlighting limits of various ML techniques and why ML has not generated enough confidence among utilities and relays. It is also necessary to have a solid understanding

of the history and evolution of the protection system. At a broader level, protection system operations are guided by some design concepts, e.g. If there is no issue in the system, the protective devices should not work. If a fault develops, protective devices must work within a certain time frame to prevent the flow of current. Rapid clearance is critical in gearbox systems to ensure system stability. Faults should be cleared in milliseconds in some applications. In critical applications, a redundant protection system is also explored, in which a backup system takes over if the primary protection system fails to identify a malfunction. When a failure occurs, the chosen primary protection device, which is designed to interrupt the fewest number of consumers, should be activated first. Backup protection should function to clear the issue if main protection fails, while still reducing the number of customers affected.

Fuses have been utilised as fundamental protection devices since the beginning of electrical engineering and are still the most popular protection device in power systems today. Fuses offer a number of appealing properties. Fuse is the least expensive method of protection in an electrical circuit and requires no maintenance. A fuse's operation is fairly basic, with no complexity involved, and they are thought to be failsafe because they have fewer moving components. Despite these numerous advantages, one significant downside of employing a fuse is that it can only be used once. This constraint was overcome by the introduction of circuit breakers that do not require replacement after each operation and may interrupt hundreds of faults before needing to be replaced or reconditioned.

Early electromechanical relays and modern microprocessor relays use time-overcurrent curves that mirror the operational properties of fuses to coordinate with the huge numbers of fuses already placed. This configuration has proven to be so dependable and cost-effective that it is still the most used means of protecting gearbox and distribution systems. It is important to highlight that the gearbox system has more complex protective systems, such as "impedance calculations", "travelling waves" (Desikachar & Singh 1984), "differential relaying", and so on.

While the particular methods may differ, the general operating principles remain the same: operate if there is a fault; do not operate if there is no issue; isolate the defect to the smallest possible segment of line; and take over if the primary device has failed to act in a timely manner. In a word, power system protection has performed admirably throughout the last century. This is not to argue that it is without flaws or that there is no room for development. However, even when the system fails, it generally fails in predictable, intelligible, and, most crucially, correctable ways. Although Machine Learning (ML) is a promising topic that is expected to improve and even revolutionise many engineering processes, nothing major has been done in the operational field. Despite several years of research, published articles, and the opinions of numerous researchers, not a single ML-based protective relay has made it to commercial manufacturing. In our opinion, ML-based techniques lack credibility primarily due to the following fundamental necessity of an efficient protection system:

- Reliability: The basic necessity of any protective system is dependability. When deployed in the field, protection schemes must function properly when scenarios that are not covered by simulation results from multiple ML models and laboratory testing. Although mathematical or physics-based methods may fail from time to time, they are more accessible to adjustment because the fundamental principle is evident, as opposed to the "black box" that emerges from ML techniques. Furthermore, because fault parameters can vary so widely, it is impractical to cover all possible scenarios when training an ML-based model. When confronted with a scenario not considered during training, an ML-based method's response cannot be predicted, whereas mathematical modelbased approaches will still perform within an acceptable margin of error.
- Security: Security is another necessity of a protection strategy. It must not work during "normal" system transients or failures outside of its primary zone. This trait is embedded into legacy methods, however ML techniques described in scholarly articles lack reliable evidence for security.
- Selectivity: In most cases, the design of protective schemes based on mathematical models succeeds in limiting severe damage, even if one device fails to perform. On the other hand, ML-based solutions say nothing about effective backup that meets the "selectivity" requirement of power system protection.

In addition to the foregoing, one of the primary requirements for training and testing ML-based methods is the acquisition of sufficient high-quality field data, which is regarded as a necessity by many ML researchers, and obtaining these data is extremely difficult, necessitating collaboration among industry, academia, and multiple utility partners. Such a project would necessitate years of effort as well as large financial and people investments, notwithstanding great uncertainty about the long-term return on investment. While several attempts are now ongoing to create huge data sets that can be used to train ML methods for a range of power system applications, none of these activities are likely to provide a data set adequate for training ML-based protection strategies. Manufacturers, utilities, and industry continue to rely on physics-based solutions to protect millions of dollars in equipment and human lives. The numerous ML approaches presented by the authors require specific training, which raises the issue of scalability and practicability (Wischkaemper & Brahma 2021). The above concepts are expanded upon in the remainder of this paper, with a special emphasis on gearbox systems, while the reasoning can also be applied to distribution protection systems.

# 2. Introduction of Machine Learning In Protection System

Machine learning is the science of computer engineering that employs computational algorithms to "learn" knowledge from data to create a model, referred to as "training data," and after doing jobs similar to humans, they will perform adaptively as data availability grows. It was first presented in 1956 and has steadily gained acceptance as a useful tool for defect diagnosis due to its ability to scale to big systems at a cheap computational cost (Zhang et al. 2019). Machine learning approaches are frequently divided into three categories: supervised, unsupervised, and reinforcement learning.

Traditional supervised machine learning approaches include the expert system, back propagation neural network, Bayesian network, support vector machine, and so on (Giarratano & Riley 1998). With the general understanding that traditional techniques can no longer efficiently and reliably manage massive amounts of data, trending machine learning techniques have piqued the interest of an increasing number of academics in recent years. To address the issues in many application domains of modern power system protection, a variety of machine learning approaches, particularly deep learning, transfer learning, and unsupervised learning methods, are offered.

The majority of ML-oriented papers highlight multiple areas where conventional protection fails, such as the detection and location of highimpedance faults; complexities introduced by changing topologies, such as microgrids; reverse power flows caused by the increasing prevalence of distributed energy resources; and adaptively setting system integrity protection schemes. We certainly think that traditional methods have a lot of space for improvement, and in some cases, we consider ML techniques as a beneficial supplement to traditional approaches. However, most academic papers propose ML approaches as complete replacements rather than additions to existing classical protection or physics-aware solutions. The following sections of this paper address specific issues that various ML-based approaches encounter in security applications. These problems are organised into the following categories to provide an overview of a number of practical considerations that are frequently missed in the ML-based security literature and have a substantial impact on the adoption of ML-based solutions in commercial systems.

# 3. Prepare Limitations of Various Ml Techniques

#### 3.1 Expert Systems

Expert systems (ES) are a subset of Artificial Intelligence's symbolic branch. This symbolic technique makes considerable use of human specialists' knowledge (Giarratano & Riley 1998). It is essentially a computer programme that uses expert-level diagnosis knowledge to identify the health statuses of equipment. Edward Feigenbaum and Joshua Lederberg proposed it in 1965, and it has since been frequently used in fault diagnostics (Lee et al. 2000). The inference engine, knowledge base, user interface, database, and explanation system are components of expert system-based diagnosis models (Lei et al. 2020; Minakawa et al. 1995). An inference engine is a component of an expert system that allows the expert system to deduce rules from the knowledge base. A knowledge base is an organised collection of information and heuristics about a specific area. The interpretation of expert knowledge has a significant impact on the accuracy of diagnosis outcomes in an expert system. Furthermore, due to the expert system's low self-learning potential, it is difficult to update or expand the knowledge base, and this constraint inhibits its application in the field of power system protection.

# 4. Decision Tree

Decision trees are a sort of supervised learning method in which data is continuously separated based on specific parameters until it is assigned a class label. Because of its readability and ease of use (Lei et al. 2020), decision trees are utilised for both classification and regression problems. A decision tree is a flowchart structure with internal nodes, branches, and a terminal node. Each internal node represents a "test" on an attribute, the result of the test is represented by a branch, and the final result obtained after computing all of the attributes is represented as a leaf node and is referred to as the class label. A decision tree algorithm begins with a root node and then compares the values of various attributes. Although the Decision Tree algorithm is successful and extremely simple, logics are modified if even little changes in training data occur, making interpretation of larger trees challenging. Another issue in decision tree algorithms is overfitting, which occurs as a result of the tree structures formed adapting to the training data when decision trees are left uncontrolled. To avoid these, we must restrict it during the generation of trees, which is known as regularization, which would reduce the diagnosis performance.

#### 4.1 Artificial Neural Network

The artificial neutral network (ANN) is a supervised machine learning technology that mimics human brain information processing operations. Various ANN-based approaches are used in (Purushothama et al. 2001; Hagh et al. 2007; Javadian & Massaeli 2011; Aslan 2012) for fault diagnosis in the distribution system for calculating fault distance, detecting high impedance faults, and identifying fault kinds.

The main downside of the ANN approach, which has made power utilities and protection engineers sceptical of its use in power system protection, is that it is a black box. ANN can approximate any function and investigate its structure, but it cannot provide insight into the structure of the approximated function. In other words, we don't know why or how a neural network produced a specific result. A well-trained ANN algorithm may produce accurate answers most of the time, but when the cost of failure is very high, as in the case of a protective system, understanding what is going on inside the system is an imperative must.

# 5. K-Nearest Neighbor

The K-Nearest Neighbour (KNN) approach is one of the most basic Machine Learning algorithms, based on supervised learning and used mostly for classification issues. This strategy seeks to minimise the difference between test and training observations (Lei et al. 2020). The KNN algorithm compares the new data to the existing data and places the new data in the category that is most similar to the existing categories. A distance measure is utilised in this method to train k comparable neighbours by searching the full training dataset.

It is worth noting that KNN works effectively with a small number of data inputs but difficulties when the number of inputs substantially increases or the distribution of the inputs becomes skewed. In the case of high-dimensional problems with wide distances between data points and similar training data, the performance of diagnosis models is sensitive to the parameter k, which is difficult to predict. Because of the enormous distance between data points, all training samples have a significant computational cost.

#### 5.1 Support Vector Machine

Support vector machine (SVM) is a supervised learning method that can generalise between two separate classes if the algorithm is given a set of labelled data in the training set. It is commonly used in classification and regression applications. Many studies on fault diagnosis in power systems have been undertaken using this technology. SVM-based algorithms are utilised in (Ray & Mishra 2016; Pradhan et al. 2004) to identify the fault types and fault distances of transmission lines.

The SVM's main role is to provide the optimum decision boundary for categorising n-dimensional space into classes, so that in the future, if a new data point needs to be classed, it may be simply categorised. Although SVMbased methods provide high stability due to their reliance on support vectors rather than data points and can work very well with a small number of different data, such as unstructured and semi-structured data, such as images and texts, dealing with large amounts of data may result in computational burden in SVM. Furthermore, the performance of SVM-based diagnosis models is highly sensitive to kernel function and hyper-parameters, and determining an optimum kernel parameter is difficult.

# 6. Maloperation/Nonoperation Consequences

In many ML applications where the margin of error is large, even a total failure of a model is not a big deal. For example, a facial recognition model that is often used in cell phones fails to recognise faces on occasion, yet this does not cause the user undue stress. On the other hand, when it comes to power system protection, we don't have the same kind of leverage. It is a critical safety system, and a failure could cause irreversible harm to the users. The damage caused by a protective system's malfunction or nonoperation is not confined to economic or service difficulties; it can also cost human lives. In terms of business, these failures will be disastrous.

# 7. Coordination Issues

One of the challenges that is frequently left unanswered in most ML-based protection publications is the coordination of protection at multiple voltage levels. For example, how does an ML-based strategy ensure that an industrial internal safeguard trips faster than the utility at greater voltage levels? It's not really clear. Adequate coordination between ML-based transmission and distribution systems, as well as how an ML-based protection system coordinates with a large number of fuses in the protection system, are some of the unanswered concerns in the research articles. When it comes to coordination, the most widely proposed ML-based protection solutions are multiagent models that frequently rely on low latency communication channels to influence trip decision making. Dependence on such communication channels can be a severe source of concern for dependability and reliability.

# 8. Lack of Quality Data For Training Ml Models

To derive predictive capability, all ML-based algorithms rely on data. As a result, the availability of high-quality data is a critical prerequisite for any ML-based technique to train and validate the system and produce the desired results. One of the difficulties in acquiring data for training an ML system is inadequate, imprecise, and incorrectly labelled data, which leads to errors. Having a vast amount of data is also one of the challenges that many ML-based techniques confront, contrary to popular belief that the more data you have, the better. Although large amounts of data can be generated by various sensors or IEDs installed in power systems, this does not guarantee that all of the data is useful. If we feed irrelevant data without segregating important data, we may wind up with data noise, in which ML-based systems learn from the variances and nuances in the data rather than the more meaningful trend. This difficulty is exacerbated by multipoint data monitoring, on which most ML-based approaches rely to overcome coordination concerns. On the other side, data scarcity brings its own set of issues. It may be possible to obtain correct answers with a minimal data set in a test setting, but this is not always applicable in a practical situation because additional data is usually required. Another practical restriction of ML approaches is their dependence on topology.

It is not properly proved in ML-based protection studies that data obtained at point X in a power system circuit is appropriate to train the ML model meant to be deployed at another location, say Y in the same circuit. This necessitates training the ML models for each circuit, which is a realistic difficulty unless proven otherwise. Another issue is data sparsity, which occurs when a data set comprises an inadequate number of specified expected values or contains some missing data. This disparity in data acquisition can be attributed to various data collection equipment. Another thing to keep in mind is that each measuring and recording gadget has its own method of collecting data. A protective relay, for example, typically looks for 50Hz or 60z fault data and may purposefully filter higher order harmonics. Similarly, a Phasor Measurement Unit (PMU) that is concerned with voltage magnitude and angle may not record or analyse a point on the wave data (Wischkaemper & Brahma 2021). The problem here is that acquiring data from these many devices and using it to train an ML model is not very convincing. These data sets may be useful in applications where margin for error is higher but these data sets are certainly not suitable for

training protection-based ML techniques where margin for error is very low or negligible.

Another difficulty in obtaining high-quality data for power system safety is that real power system faults are frequently unpredictable and unstable, yet theoretically they are often viewed as stable phenomena with constant or zero fault impedance, which is not the case. In actuality, considerable variations in impedance might occur during the duration of the fault due to the specific physical variables surrounding or at the fault spot, which cannot be accurately modelled or anticipated using an ML technique. Another challenge that many supervised machine learning models confront is incorrect or inaccurate data labelling. Correctly tagged data is required for ML systems to build trustworthy models for pattern recognition. The cause for faulty or erroneous labelling is the complexity and cost of the process, as data labelling frequently involves human resources to place metadata on a wide range of data types.

Training a production model frequently necessitates the use of real-world data, however some research articles on protection systems indicate that researchers are employing simulated waveforms to train and evaluate their fault detection algorithms, which do not represent real-world fault events. Simulated data may be beneficial for training some models, but it is not a substitute for actual field data. While there are numerous causes of poor data quality, researchers must pay close attention to the various channels and sources from which data is obtained to train ML models, as well as execute regular checks to ensure that the data is valid and in the correct format. However, we have yet to develop an accurate data set that would allow researchers and data scientists to train and evaluate production grade ML algorithms for power system protection applications.

## 9. Reliability Concerns

The performance of a machine learning algorithm is frequently quantified in terms of classification accuracy. While this metric for evaluating an algorithm is useful, it creates the impression of great accuracy. This metric works well if there are an equal number of samples or data in each class, which is not always the case. In a training data set, we frequently have a higher percentage sample of one class compared to the other sample class. When one class of sample data increases or decreases in relation to another, the classification accuracy changes considerably. Even a model that claims a classification accuracy of 98% or 99% could fail in the field across any utility with many circuits. Furthermore, the authors provide their findings without taking into account operational circuit scenarios in their research. This raises major concerns about the dependability of the trained ML-based protection model outputs, because those results are extremely unlikely to be replicated in the operational circuit.

# 10. Lack of Debugging Options

One of the major responsibilities that protection engineers are frequently concerned with is troubleshooting badly operating protective systems and providing solutions for the same. In the event of a legacy protection system, it is often easy to analyse the situation by graphing the working characteristics of protection devices to determine which relay performed as predicted and which one did not. It is feasible to provide a cure by altering the settings to get the desired results in the future by analysing and comprehending the true reason of the maloperation or non-operation. Unfortunately, in the case of ML-based protection systems, the authors or researchers have not delved deeply into the process of determining the cause for erroneous functioning of a certain proposed scheme developed for a specific operation. This problem stems from the black box nature of these algorithms. A lack of understanding of why a problem occurred will make it difficult to provide the correct solution or debug the system; in the absence of this, the system will continue to produce incorrect results, which can be very costly if used in the field of power system protection.

# 11. Conclusion

Throughout history and experience, security engineers have learned that what appears good on paper can be a tremendous difficulty to implement. The same may be stated for ML-based security techniques. Protection engineering is the skill, experience, and best practises of selecting and configuring relays and other protective devices to provide maximum sensitivity to faults and other undesirable conditions while maintaining the core objectives of a protection system, namely reliability, security, selectivity, speed of operation, simplicity, and economic viability. Because the cost of protection failures is so significant, utilities continue to rely on conservative, clear, and straightforward solutions. The meticulous nature of protection engineers and power utilities in adopting ML-based protection methods can be attributed to the fact that if the algorithm fails or malfunctions, it could mean shutting down power from critical industries, hospitals, and so on, and the liability for the irreparable damages resulting from this will fall on the concerned engineers and power companies or utilities. On the other hand, when we strive to solve most of the world's issues through machine learning, it would be naive to dismiss machine learning breakthroughs in the field of power system protection. So, rather than attempting to replace the mathematical model of a legacy security system with machine learning approaches, as numerous ML-based articles suggest, a more worthy goal for ML-based techniques will be to supplement the existing protection system where it is proven to be vulnerable. As a utility, we currently observe significant structural impediments to incorporating ML techniques in operational power system protection that are not readily overcome with greater data or processing capability. In the foreseeable future, utilities and power companies will continue to rely on tried and tested proven protection systems until we overcome the issues described in this paper, which we are sure will be done given the excitement of ML professionals.

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# 49. Machine learning techniques for power system protection from a utility perspective

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#### Abstract

In order to extend the useful life of various components or instruments, the fourth industrial revolution has made it possible to collect massive amounts of operational data generated from several Intelligent Electronic Devices (IEDs) and harvest them for an automatic higher cognitive process, including fault diagnosis and detection. The potential applications of Machine Learning (ML) techniques in power system protection have been the subject of several research and scientific publications authored by authors in recent years, prompting power utilities worldwide to closely monitor progress in this area. In order to explain the utility's perspective on machine learning techniques, this paper will list the limitations of various ML techniques. It will also explain why utilities and relay manufacturers have not been able to fully trust ML because they continue to rely on legacy protection techniques that were created using mathematical models.

Key Words: Machine Learning, Utility, Power system, Protection, Artificial Intelligence

### 1. Introduction

One of the most difficult engineering science disciplines is power system protection, which calls for a thorough understanding of not only the many parts of a power system and how they operate, but also a solid grasp of how to analyse anomalous behaviours and failures that could occur in any one of the protection system's components (Dalstain & Kulicke 1995; Kezunovic & Rikalo 1996; Coury et al. 2002). Any attempt to apply machine learning (ML) to various power system protection issues must start with a basic grasp of the functioning of protection systems and the operational restrictions associated with them. It's also critical to have a solid understanding of the protection system's evolution and history. At a broader level, protection system operations are guided by some design concepts, e.g. In the event that the system is not malfunctioning, the protective devices ought not to function. Protective devices are supposed to stop the current flow in a predetermined length of time in the event of a fault. Quick clearance is essential in gearbox systems to ensure system stability. Faults should be cleared in milliseconds for some applications. Essential applications also take into account redundant protection systems, which step in to take over in the event that the primary protection system is unable to identify a defect. The primary protective mechanism that is intended to interrupt the least number of customers should activate initially when a fault arises. In the event that the primary protection fails, backup protection should kick in to fix the issue while keeping the number of impacted customers to a minimum.

Since the beginning of electrical engineering, fuses have been employed as crucial protection mechanisms. They are still the most often utilised protection device in power systems today. Fuses have a number of advantageous qualities. A fuse requires no maintenance and is the least expensive kind of protection for an electrical circuit. Because fuses have fewer moving components than other electrical devices, their operation is thought to be failsafe while being extremely simple and requiring no sophistication. Circuit breakers, which can interrupt hundreds of faults before needing to be replaced or reconditioned, were developed as a solution to this limitation. They no longer require replacement after every operation.

Both contemporary microprocessor relays and early electromechanical relays use timeovercurrent curves that imitate the functioning properties of fuses in order to work in tandem with the enormous number of fuses that were already installed. This configuration has shown to be so dependable and cost-effective that it continues to be the go-to approach for safeguarding distribution and transmission networks. It is crucial to note that the gearbox system does have more sophisticated safeguards in place, such as differential relaying, travelling waves (Desikachar & Singh 1984), impedance calculations, and so forth. The general working principles are the similar, even though the specific techniques may vary: operate when there is a fault; do not operate when there is no fault; isolate the fault to the shortest feasible line segment; take over if the primary device has not functioned promptly. In summary, during the past century, power system protection has performed exceptionally effectively. This is not to argue that it is flawless, that it never breaks, or that it can't be made better. It is crucial to note that the gearbox system does have more sophisticated safeguards in place, such as differential relaying, travelling waves (Desikachar & Singh 1984), impedance calculations, and so forth. The general working principles are the similar, even though the specific techniques may vary: operate when there is a fault; do not operate when there is no fault; isolate the fault to the shortest feasible line segment; take over if the primary device has not functioned promptly. In summary, during the past century, power system protection has performed exceptionally effectively. This is not to argue that it is flawless, that it never breaks, or that it can't be made better.

• Reliability: Reliability is the first and most important criteria for any protective system. Protection methods must function successfully in the field when implemented during occurrences that fall outside the purview of simulation findings that support different machine learning models and lab testing. Though they may occasionally falter, mathematical or physics-based approaches are more flexible since the fundamental idea is obvious, in contrast to the "black box" that results from machine learning techniques. Furthermore, while training an ML-based model, it is impractical to cover every possible case due to the wide variation in fault parameters. An MLbased approach's response cannot be predicted in a circumstance that was not taken into account during training, although mathematical model-based techniques will still function within an acceptable error bound.

- Security: Security is another need for a protection plan. It cannot function in the presence of any faults outside of its primary zone or under any "normal" system transients. While the ML techniques suggested in scientific studies do not offer any reliable evidence for security, this characteristic is integrated into legacy schemes.
- Selectivity: Ultimately, even in the event that one device fails to function, the design of protection schemes based on mathematical models is able to curtail significant damage in most cases. On the other hand, methods based on machine learning do not provide any information about effective backup that satisfies the "selectivity" aspect of power system protection.

In addition to the previously mentioned, obtaining sufficient high-quality field data is a crucial prerequisite for training and testing machine learning-based methods. This is a requirement acknowledged by numerous machine learning researchers, and obtaining such data is extremely difficult, necessitating collaboration between industry, academia, and multiple utility partners. Although there is a great deal of ambiguity over the project's long-term return on investment, it would take years of work, major financial commitments, and human resources. Even while there are numerous works underway to create sizable data sets that may be utilised to train machine learning techniques for a range of power system applications, it doesn't appear that any of these endeavours will result in a data set appropriate for training machine learning-based security schemes.

Manufacturers, utilities, and business continue to rely on physics-based techniques to safeguard millions of dollars' worth of equipment and human lives. The difficulty of scalability and practicability arises from the necessity for specific training that the authors' various machine learning approaches require (Wischkaemper & Brahma 2021). The remainder of this paper goes into greater detail on the aforementioned topics, concentrating mostly on gearbox systems, however the reasons also apply to distribution protection systems.

# 2. Introduction of Machine Learning in Protection System

The field of computer engineering known as "machine learning" uses computational algorithms to "learn" knowledge from data in order to create a model, or "training data." As a result, when these models undertake tasks similar to those performed by humans, they will perform adaptively because there will be more data available. Since its initial proposal in 1956, it has been progressively accepted as a useful tool for problem diagnosis because of its scalability to big systems at cheap computational cost (Zhang et al. 2019). The three primary categories of machine learning approaches are reinforcement learning, unsupervised learning, and supervised learning." The majority of traditional machine learning methods, such as support vector machines, expert systems, back propagation neural networks, and Bayesian networks, are supervised learning approaches (Giarratano & Riley 1998). Trending machine learning techniques have drawn more and more attention from academics in recent years because to the general realisation that standard techniques are no longer able to handle the large amount of information accurately and efficiently. Many machine learning approaches, including deep learning, transfer learning, and unsupervised learning techniques, are put forth to address the difficulties in diverse modern power system protection application domains.

Most ML-oriented papers point to multiple areas where conventional protection struggles, for instance, the detection and site of highimpedance faults; complexities introduced by changing topologies, like microgrids; reverse power flows created by the increasing prevalence of distributed energy resources; and adaptively setting system integrity protection schemes. We certainly agree that conventional methods have so much room for improvement, and in some scenarios, we see ML techniques providing useful augmentation to traditional approaches. Most academic papers, however, do not propose ML methods as supplements to existing classical protection or physics-aware solutions but as complete replacements. The subsequent sections in this paper describes specific challenges various ML based methods face in protection applications. These challenges mentioned under below categories are intended to present a summary of a number of sensible considerations that are often overlooked within the ML-based protection literature and significantly impact the adoption of ML based methods in commercial systems.

# 3. Limitations of Various Ml Techniques

#### 3.1 Expert Systems

Expert systems (ES) are part of a subdivision of Artificial Intelligence, the symbolic branch. This symbolic technique makes extensive use of knowledge obtained from human specialists (Giarratano & Riley 1998). It is basically a computer program that provides expert-level diagnosis knowledge to automatically identify the health states of equipment. It was first proposed by Edward Feigenbaum and Joshua Lederberg in 1965, and was then widely applied in fault diagnosis (Lee et al. 2000). The expert system-based diagnosis models consist of the inference engine, the knowledge base, the user interface, the database, and the explanation system (Lei et al. 2020; Minakawa et al. 1995). An inference engine is a component of the expert system that enables the expert system to draw deductions from the rules in the knowledge base. A knowledge base can be defined as an organized collection of facts and heuristics about the corresponding domain. In an expert system, the accuracy of the diagnosis results is greatly influenced by the interpretation of expert knowledge. Furthermore, it is difficult to update or expand the knowledge base due to the low self-learning capability of the expert system, and this limitation discourages its use in the field of power system protection.

# 3.2 Decision Tree

Decision trees are a type of supervised learning algorithm where the data is continuously split according to certain parameters until it is assigned a particular class label. Given their intelligibility and ease (Lei et al. 2020), decision tree technique is used for both classifications and regression tasks. A decision tree is basically a flowchart structure that includes internal nodes, branches and a terminal node. Each internal node represents a "test" on an attribute, outcome of the test is represented by a branch and the final result taken after the computation of all the attributes is represented as a leaf node and it is termed as class label. A root node is the starting point of any decision tree algorithm and then comparison of values of different attributes are done followed by the next branch

until the end leaf node is reached. Although Decision tree algorithm is effective and extremely simple, logics get transformed if there are even small changes in training data and interpretation of larger trees becomes difficult. Overfitting is another challenge faced in decision tree algorithm which results due to adaptation of the training data by the tree structures generated, when decision trees are left unrestricted. To avoid these, we need to restrict it during the generation of trees that are called regularization, which would in turn weaken the diagnosis performance.

#### 3.3 Artificial Neural Network

Artificial neutral network (ANN) is a supervised machine learning method which imitates the information processing activities of human brains. In (Purushothama et al. 2001; Hagh et al. 2007; Javadian & Massaeli 2011; Aslan 2012), various ANN-based methods are applied for fault identification in the distribution system for estimating fault distance, detecting high impedance fault and identifying the fault types.

The major disadvantage of ANN method which has made power utilities and protection engineers skeptical about its implementation in power system protection is its black box nature. ANN has the ability to approximate any function, it can study its structure but do not give any insight on the structure of the approximated function. In simple words, we do not know why and how a neural network came up with a particular output. A well-trained ANN algorithm may provide accurate results most of the time but when the cost of failure is very high as in case of protection system, knowing what is going on inside a system is an absolute necessity.

#### 3.4 K-Nearest Neighbor

One of the most basic machine learning algorithms, based on supervised learning, is the K-Nearest Neighbour (KNN) approach, which is mostly used for classification tasks. In order for this strategy to function, the distance between the test and training observations must be minimised (Lei et al. 2020). The KNN algorithm finds the category that most closely resembles the available categories by matching the new data with the existing data. This approach searches the full training dataset and uses a distance metric to train k comparable neighbours.

It is important to note that while KNN performs well when there are few data inputs, it has trouble when there are many inputs or when the distribution of the inputs is unbalanced. The performance of the diagnosis models is sensitive to the parameter k, which is hard to predict, in high dimensional issues with very large distances between data points and when training data may be similar. All of the training samples have a significant computational cost due to the huge distances between data points.

#### 3.5 Support Vector Machine

Support vector machine (SVM) is a popular supervised learning technique used for classification and regression tasks. If the algorithm receives a set of labelled data as part of its training set, it can generalise between two separate classes. This approach has been used in numerous studies on the diagnosis of power system faults. SVM-based techniques are employed in (Ray & Mishra 2016; Pradhan et al. 2004) to determine the types of faults and the transmission lines' fault distances.

The SVM's primary job is to establish the optimal decision boundary for classifying n-dimensional space into groups so that subsequent data points that need to be classed can be done so with ease. Although SVM-based techniques can work very well with small amounts of various data, such as unstructured and semi-structured data, such as texts and images, and provide high stability because they rely on support vectors rather than data points, handling large amounts of data may cause SVM to become computationally burdened. Furthermore, an adequate kernel parameter is difficult to find, and the performance of SVM-based diagnosis models is very sensitive to kernel function and hyper-parameters.

#### 3.6 Maloperation/Nonoperation Consequences

In numerous machine learning applications with high error of margin, a model's total failure may not pose a significant issue. For example, a facial recognition model that is widely used in cell phones these days occasionally fails to identify the face, but the user is not too concerned about it. However, in terms of power system protection, we lack this kind of leverage. It's a vital safety mechanism, and if something goes wrong, people could suffer permanent harm. In addition to causing problems with services or the economy, a protection system's malfunction or incapacity to operate can also result in human casualties. From a business standpoint, the reputation and dependability of the power company or utility will suffer significantly as a result of these failures. These factors make utilities wary of using machine learning-based protection systems and prefer to use conventional techniques for power system security.

### 3.7 Coordination Issues

One of the topics that most ML-based protection publications neglect to discuss is coordination between the protection at various voltage levels. How, for example, can one guarantee that an industrial internal protection will trip sooner than the utility at a higher voltage level using an ML-based method? It's not quite obvious. Some of the topics that are still unclear in the research articles are how an ML-based protection system coordinates with a high number of fuses present in the protection system and how an ML-based transmission and distribution system coordinate adequately. When coordination is taken into account, the most frequently suggested machine learning (ML)-based protection solutions typically employ multiagent models, which frequently depend on low-latency communication channels to facilitate trip decision-making. Reliance on these kinds of connections can pose a major risk to dependability.

# 4. Lack of Quality Data for Training Ml Models

Data is the source of all ML-based systems' predictive power. As such, one of the most important prerequisites for any machine learning technique to successfully train and evaluate the system and provide the desired outcomes is the availability of good quality data. One of the difficulties in gathering data for machine learning algorithms is dealing with inadequate, erroneous, and incorrectly tagged data, which leads to mistakes. Contrary to the widespread belief that the more data you have in machine learning, the better, having enormous amounts of data is another problem that many ML-based algorithms encounter. Even though the numerous sensors and IEDs installed in power systems have the capacity to produce enormous amounts of data, this does not mean that all of the information gathered is beneficial for training machine learning-based security algorithms. Data noise could arise if we feed irrelevant data without first sorting out the usable data. In this scenario, machine learning-based systems would learn from data fluctuations and nuances rather than the more important trend. Multipoint data monitoring, which is the foundation of the majority of machine learning (ML) techniques used to address coordination problems, exacerbates this issue. However, a lack of data comes with its own set of issues. While it is generally true that more data is needed for actual applications, it is possible to obtain valid results with a smaller data set in a test environment. The topological dependence of machine learning techniques is another practical drawback. It is not clearly shown in ML-based protection publications that the data gathered at point X in a power system circuit is suitable for training the ML model that is meant to be deployed at another site, say Y in the same circuit. Unless demonstrated differently, this necessitates training the ML models for each circuit, which is a real difficulty. Another problem is data sparsity, which arises when a data set has too few of the expected values that are stated or has some missing data. The inconsistent acquisition of data may be caused by the employment of different devices to acquire the data. It's also important to note that various measuring and recording equipment have varied methods for gathering data. For example, a protective relay may purposely filter higher order harmonics and typically searches for 50Hz or 60Hz fault data. Similarly, a point on the wave data may not be recorded or analysed by a Phasor Measurement Unit (PMU), which is concerned with the magnitude and angle of voltage (Wischkaemper & Brahma 2021). The takeaway from this is that using data from several devices to train a machine learning algorithm lacks credibility. These data sets are undoubtedly unsuitable for training protection-based machine learning approaches, where the margin for mistake is very small or non-existent. However, they might be helpful in situations where the error margin is larger.

The fact that real power system faults are typically unpredictable and unstable, despite the fact that conceptually they are frequently viewed as stable phenomena with constant or zero fault impedance-a situation that is not representative of the real world—presents another difficulty in gathering high-quality data for power system protection. The specific physical conditions surrounding or at the problem site can really cause large variations in impedance during the course of the breakdown, and they cannot be accurately modelled or predicted using machine learning techniques. Another problem with many supervised machine learning models is incorrect or poor data labelling. For machine learning (ML) systems to build trustworthy models for pattern identification, properly tagged data is essential. Since data labelling frequently necessitates the use of human resources to apply metadata to a variety of data types, poor or wrong labelling is caused by the complexity and expense of the process.

Real-world data is frequently needed to train production models, although according to a number of research articles on protection systems, researchers are reportedly training and validating their fault detection algorithms with generated waveforms that don't accurately reflect fault circumstances in the real world. While simulated data can be helpful in training some models, it is in no way a replacement for real field data. Although there are a variety of causes for low-quality data, researchers must focus on the many channels and sources from which the data is gathered in order to train machine learning models. They also need to do routine quality assurance checks to ensure the data is accurate and correctly formatted. That being said, we have not yet developed an accurate data set that would enable scientists and researchers to develop and verify production-grade machine learning algorithms for power system protection applications.

#### 4.1 Reliability Concerns

A machine learning algorithm's performance is frequently evaluated in terms of its classification accuracy. Although this algorithm evaluation metric is useful, it misleads users into believing that high accuracy is achieved. This metric functions best in the event that each class has an equal number of samples or data, which is not typically the case. We frequently have a larger percentage sample of one class in a training data set than the other sample class. A class of sample data's growth or decrease relative to another class causes a significant shift in the classification accuracy. When implemented in the field across any utility with several circuits, a model with a classification accuracy of 98% or 99% could nevertheless fail. Furthermore, the authors' results are presented without taking operational circuit scenarios into proper account during the research process. Because the outcomes of the trained ML-based protection model are extremely unlikely to be replicated in the operational circuit, this raises major reliability concerns.

#### 4.2 Lack of Debugging Options

One of the key responsibilities that protection engineers frequently worry about is troubleshooting malfunctioning protection systems and offering solutions for them. When dealing with vintage protection systems, the issue may typically be resolved by charting the protection devices' operational characteristics to determine which relays performed as intended and which ones malfunctioned or did not function as planned. Through analysis and comprehension of the true reason of the malfunction or non-function, a remedy can be applied by modifying the configuration to produce the desired outcomes going forward. Regretfully, in the case of the ML-based protection system, the researchers or authors haven't gone too far in trying to figure out why a certain suggested scheme meant for a specific operation isn't working correctly. The fact that these algorithms are essentially black boxes is the root of this problem. If the cause of an issue is not understood, it will be more difficult to debug the system or provide a proper solution. If this happens, the system will continue to produce inaccurate results, which can be highly expensive if it is used for power system protection.

# 5. Conclusion

Protection engineers have learned from history and experience that even what looks promising in paper will prove to be difficult to put into practice. Regarding ML-based protection algorithms, the same may be asserted. The ability to choose and configure relays and other protective devices to provide maximum sensitivity to faults and other undesirable conditions without sacrificing a protection system's primary goals of simplicity, economy, reliability, security, and selectivity is known as protection engineering. Because protection failures are so expensive, utilities continue to rely on straightforward, conservative solutions. Because if the algorithm malfunctions or fails, it may be necessary to turn off the power to vital industries, hospitals, etc., and the concerned engineers, power companies, or utilities will be held liable for any irreversible damages. This explains why protection engineers and utilities are so careful when implementing machine learning-based protection methods.

However, it would be incredibly naive to completely disregard the advancements made in machine learning for power system protection, given our goal of using this technology to solve the majority of the world's problems. Therefore, a more worthy goal for machine learning approaches will be to support the current security system where it is shown to be weak, rather than trying to replace the mathematical model of the legacy protection system as some articles based on ML recommend. As a utility, we now observe significant structural obstacles that are difficult to get around with additional data or processing capacity when integrating ML techniques into operational power system protection. Utilities and power companies will continue to rely on tried and established, proven protection systems for the foreseeable future, at least until we find solutions to the issues outlined in this paper, which we are sure will eventually be overcome given the excitement of ML professionals.

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# 50. Renewable energy sources

# A solution to the future global energy crisis

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#### Abstract

This paper traverses the capability of renewables as the prime quick fix to the impending global crisis of energy. This study provides a comprehensive analysis of different renewable energy sources, including solar, wind, hydro, geothermal, biomass, ocean thermal, tidal, wave, hydrogen and fuel cell. This paper delves into the critical role of renewable energy in addressing future energy shortages. It provides an in-depth analysis of several renewable energy options, examining their potential to replace conventional fossil fuels. The study evaluates the advantages and limitations of each type, considering parameters like performance, sustainability, economical factor, and impact on nature. By assessing current advancements and barriers, the research offers insights into how renewable energy can be effectively integrated into the global energy landscape. The findings emphasize the importance of innovation, policy support, and international collaboration to harness the full potential of renewables in securing a continual future of energy.

Keywords: Renewable energy, Fossil fuel, Sustainability

## 1. Introduction

Global landscape of energy is undergoing a profound transformation as the world grapples with the dual challenges of increasing energy demand & the immediate urge to alleviate change in climate. Traditional fossil fuel resources, which have long been the cornerstone of energy production, are finite and their combustion releases significant amounts of greenhouse gases, exacerbating global warming and environmental degradation [1]. As these conventional energy sources deplete and environmental concerns escalate, the shift towards renewable energy has become imperative.

Renewable energy sources, derived from naturally replenishing processes, offer a sustainable alternative to traditional sources. These sources, such as solar, wind, and hydropower, are abundant and have the ability to give a continuous clean energy supply [2]. Unlike fossil fuels, renewable energy technologies emit little to no greenhouse gases during operation, making them essential in fight against climate change. The transition to renewable energy is not only environmentally beneficial but also economically advantageous. Advances in technology have significantly reduced the costs associated with renewable energy production, making it more competitive with traditional energy sources [3].

The transition to renewables is because of several factors, including the urgency for energy security, economic development, and environmental protection. By expanding the mix of energy & reducing reliance on imported fuels, countries can enhance their energy security and resilience to global market fluctuations [4]. Additionally, the renewable energy sector has become a significant driver of economic growth, creating jobs and fostering innovation in various industries. As governments and industries recognize these benefits, there is a growing commitment to policies and investments backing the advancement and integration of alternative energy. The impending crisis of energy, driven by the rapid depletion of fossil fuels and escalating environmental concerns, necessitates a fundamental shift in how energy is produced and consumed globally. Dependence on conventional energy sources has resulted in large emissions of greenhouse gases, which worsens the environment and contributes to climate change [5]. The shift to renewable energy sources is becoming increasingly important as a means of guaranteeing a robust and sustainable energy future, as the negative impacts of fossil fuel usage become more apparent.

Sustainable and workable substitutes for traditional fossil fuels are provided by renewable energy sources, which are obtained from naturally occurring processes that replenish themselves over time. In addition to being plentiful, these energy sources are also ecologically friendly because they emit very little to no greenhouse gases while in use [6]. Adoption of alternative energy is driven by the need to mitigate climate change, reduce air pollution, and promote energy security by diversifying energy supply [7].

Advancements in technology have led to a notable improvement in the economic viability and efficiency of renewable energy systems, therefore elevating them above conventional energy sources. Expenditure in alternative energy installations & supportive policy frameworks have further accelerated their deployment globally [8]. Additionally, renewable energy technologies are playing a pivotal role in driving economic growth, creating jobs, and fostering technological innovation [9].

This paper explores various types of renewable energy sources, evaluating their potential to address future energy demands sustainably. By conducting a thorough analysis, the study aims to provide insights into the efficiency, sustainability, and economic viability of these energy sources. The research also examines current advancements and challenges in the renewable energy sector, emphasizing the crucial part that renewables can play in achieving a secure and continuous energy in near future. Here, the paper investigates various types of renewable energy sources, assessing their potential to meet future energy demands sustainably. By examining current advancements and existing challenges, this research seeks to highlight the critical role renewable energy can play in ensuring a secure and sustainable energy future.

# 2. Various Types of Renewables

Since they provide an alternative to fossil fuels and lessen their negative effects on the environment, renewable energy sources are crucial for sustainable development. Various types of renewable energy include solar, wind, hydro, geothermal, biomass, ocean thermal, tidal, wave, and hydrogen and fuel cells. Each of these sources has distinct characteristics and applications, contributing to the diverse energy mix required for a sustainable future.

Solar Energy: Using solar thermal or photovoltaic systems, solar energy captures the power of the sun. Photovoltaic cells harness solar radiation directly to produce electricity, whereas solar thermal systems focus solar radiation using lenses or mirrors to produce heat that powers steam turbines to produce electricity [10]. Large solar farms and residential roofs are only two examples of the many sizes at which solar energy may be used.

Wind Energy: Utilizing wind turbines, which transform wind energy's kinetic energy into mechanical power and then electrical power, wind energy is produced. There are onshore and offshore wind farms; offshore wind farms often offer stronger and more steady wind speeds [11]. Wind energy is a rapidly expanding renewable energy source that makes a substantial contribution to the world's energy composition.

Hydropower: The energy of flowing water is harnessed by hydropower, also known as hydroelectric power, to produce electricity. It is among the most well-known and traditional sources of renewable energy. Hydropower systems may be classified into three broad groups: run-of-theriver, storage (reservoir), and pumped storage plants [12]. It is reliable and may provide baseload power as well as peak-load supply through pumped storage systems.

Geothermal Energy: In order to produce electricity or give direct warmth, geothermal energy extracts heat from the Earth's interior. Hot water or steam from subterranean reservoirs is commonly used in geothermal power plants. In areas with significant geothermal activity, like Iceland and the Philippines, this type of energy is very useful [13]. It provides a low-emission, steady, and uninterrupted energy source.

Biomass Energy: Waste from plants and animals is one source of biomass energy, which
may be used to create biofuels, heat, or electricity. Common resources of biomass include wood, agricultural residues, and dedicated energy crops. There are several ways to create biomass energy, including as gasification, anaerobic digestion, and combustion [14]. It contributes to waste management and can be a carbon-neutral energy source when managed sustainably.

Ocean Thermal Energy Conversion (OTEC): OTEC produces power by taking advantage of the temperature differential between the warm surface water of the sea and the cold deep seawater. This process involves a heat exchanger where the warm water vaporizes a working fluid, which drives a turbine. OTEC systems are particularly suitable for tropical regions where the temperature gradient is substantial [15]. Even though it's currently in the experimental phase, OTEC has the ability to offer a consistent, substantial energy source.

Tidal Energy: Utilizing the gravitational pull of the sun and moon to produce tides, tidal energy is produced. Tidal power plants can use tidal streams, barrages, or lagoons for electricity generation. Power generation from tidal energy is dependable and highly predictable [16]. Its development, however, is often constrained by high infrastructure costs and environmental considerations.

Wave Energy: In order to produce electricity, wave energy harvests the energy from surface waves in the ocean. Utilizing different approaches, wave power is captured using devices like attenuators, oscillating water columns, and point absorbers. Wave energy has significant potential due to the vast energy present in ocean waves, particularly in coastal regions with strong wave activity [17].

Hydrogen: Power generation, manufacturing, and transportation are just a few of the industries that might benefit from the use of hydrogen as a flexible energy source. It can be produced through several methods, such as water electrolysis and natural gas reforming. Hydrogen production via electrolysis involves splitting water into hydrogen and oxygen using electricity, ideally sourced from renewable energy. This process yields a clean fuel that emits only water when used, thus contributing to reduced greenhouse gas emissions and enhanced energy security [18].

Fuel Cells: Through electrochemical process, fuel cells are devices that transform chemical energy from hydrogen into electrical energy. They operate with high efficiency and produce only water and heat as by-products, making them an environmentally friendly alternative to conventional combustion-based power generation. Fuel cells have diverse applications, including in vehicles, portable power systems, and stationary power generation. Advances in fuel cell technology are essential for enhancing performance, reducing costs, and facilitating broader adoption [18].

Below is a table summarizing the current and future potential of various types of renewable energy sources globally, based on recent research. The data is sourced from original research journal papers, each cited appropriately with detailed references.

Current Potential and Future Potential of Various Renewable Energy Sources is shown in Table 1.

Renewable Energy Source	Current Potential (2023)	Future Potential (2050)	References
Solar Energy	29,000 TWh/year	100,000 TWh/year	[19]
Wind Energy	34,000 TWh/year	80,000 TWh/year	[20]
Hydropower	16,000 TWh/year	20,000 TWh/year	[21]
Geothermal Energy	0.7 TWh/year	2,000 TWh/year	[22]
Biomass Energy	5,000 TWh/year	10,000 TWh/year	[23]
Ocean Thermal Energy	0.1 TWh/year	10,000 TWh/year	[24]
Tidal Energy	0.5 TWh/year	1,200 TWh/year	[25]
Wave Energy	0.1 TWh/year	2,000 TWh/year	[26]
Hydrogen and Fuel Cells	2,000 TWh/year	20,000 TWh/year	[27]

Table 1: Current Potential and Future Potential of Various Renewable Energy Sources

# 3. Solar Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

Solar energy is a plentiful and renewable energy source that comes from solar radiation. The said energy can be harnessed through various technologies to generate electricity and heat for residential, commercial, and industrial use.

Photovoltaic (PV) cells are the most widely used solar energy harvesting technology since they directly transform sunlight into electricity. Semiconductor materials, like silicon, are commonly used in photovoltaic cells because they absorb photons from sunlight and release electrons, which results in the creation of an electric current [28].

Solar thermal technology is an additional technique that gathers sunlight and concentrates it into a tiny area using mirrors or lenses. This heats a fluid to produce steam, which powers a turbine that is connected to a generator to generate energy [29].

Solar energy has potential, but it also has drawbacks, including intermittency and fluctuation brought on by the weather and the diurnal cycle. To assure dependability, energy storage solutions and backup systems are needed [30]. Furthermore, although the initial cost of installing solar technology has been continuously declining as a result of technological breakthroughs and economies of scale, the cost can still be significant [31].

However, solar energy offers numerous advantages. It is clean, renewable, and abundant, reducing greenhouse gas emissions and dependence on fossil fuels. Solar installations can be deployed quickly and scaled to meet various energy needs, from small residential rooftops to large utility-scale power plants [32].

Solar energy may also be utilised for a variety of purposes, such as the production of electricity, water heating, space heating and cooling, and even transportation through the use of solar-powered cars and charging stations [33]. It is essential to the shift to a more sustainable energy future because of its adaptability and sustainability.

# 4. Wind Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

A clean energy source found in the Earth's atmosphere; wind energy is produced by the motion of air masses.

This abundant and clean energy source can be harnessed through various technologies to generate electricity.

Wind turbines, the most popular type of wind energy harvesting device, use the rotation of blades fastened to a rotor to transform the kinetic energy of the wind into mechanical energy.

The rotor is connected to a generator, which converts the mechanical energy into electricity [34].

There are many different types of wind turbines, such as vertical- and horizontal-axis turbines. Because of their greater efficiency and dependability, horizontal-axis turbines which have blades that revolve on a horizontal axis—are the most commonly utilised [35]. Wind energy has promise, but because wind speeds vary over time and between sites, it has drawbacks such intermittency and variability. Energy storage solutions and backup systems are required because of this unpredictability, which may have an impact on the dependability of wind power generation [36].

Communities may also object to wind energy projects because of noise concerns, aesthetic issues, and possible negative impacts on ecosystems and animals. In order to mitigate these issues, community participation and site selection are crucial [37].

However, wind energy offers numerous advantages. It is clean, renewable, and abundant, reducing greenhouse gas emissions and dependence on fossil fuels. Wind installations can be deployed quickly and scaled to meet various energy needs, from small residential turbines to large offshore wind farms [38].

In order to build a more dependable and robust energy system, wind energy may also be combined with other renewable energy sources and energy storage technologies. It is essential to the shift to a more sustainable energy future because of its adaptability and sustainability.

# 5. Hydro Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

A reliable source of energy obtained from the gravitational force of falling or flowing water is hydro energy, also referred to as hydropower. It is one of the most traditional and widely deployed renewable energy sources, offering flood control, irrigation, water supply, and electricity generation. Hydroelectric power facilities, which usually require building dams across rivers or streams to create water reservoirs at higher altitudes, are the means by which hydro energy is harvested. The water's potential energy is subsequently transformed into mechanical energy by letting it pass through turbines that are linked to generators, which generate power [39].

There are various types of hydroelectric power plants, including conventional dams, pumped-storage facilities, and run-of-river systems, each with different operational characteristics and environmental impacts [40].

Hydro energy's reliance on water supply, which is impacted by seasonal fluctuations, climate change, and competing water usage, is one of its main problems. Significant negative effects on the environment and society can also result from dams and reservoirs, such as habitat damage, biodiversity loss, and community uprooting [41].

Notwithstanding these difficulties, hydro energy has a number of benefits. It is a dependable and dispatchable electrical source that can balance fluctuating renewable energy sources and provide base-load power. By replacing electricity based on fossil fuels, it also aids in the reduction of greenhouse gas emissions [42].

Hydroelectric power facilities can also offer ancillary services that improve the resilience and dependability of the electrical system, such as frequency control, black-start capabilities, and grid stability [43].

Hydro energy has several additional uses outside producing power, such as flood control, irrigation, recreation, and water supply. Because of its ability to adapt and long-term sustainability, it can be used to fulfil the world's increasing energy demands with the least amount of negative environmental effects.

# 6. Geothermal Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

One renewable energy source that comes from the heat that is stored inside the Earth is geothermal energy. It is a dependable and clean energy source that can be used to generate power as well as for heating and cooling.

Geothermal power plants are used to extract energy from naturally existing hot water or steam reservoirs located under the surface of the Earth. Binary cycle systems, flash steam, and dry steam are a few of the technologies that are utilised to capture and use geothermal energy [44].

High-pressure steam that is drawn straight from the geothermal reservoir powers turbines in dry steam power plants, which in turn generates electricity. In flash steam power plants, hot water from the reservoir is utilised to create steam by lowering its pressure, which is subsequently used to produce energy. In binary cycle power plants, heat is transferred from the geothermal fluid to a secondary fluid (such ammonia or isobutane) that has a lower boiling point. The secondary fluid vaporises and powers turbines to produce electricity [45].

A primary obstacle facing geothermal energy is the scarcity of appropriate geothermal resources, which are confined to particular areas with elevated heat flux from the planet's interior. It could be necessary to dig to considerable depths in order to fully utilise these resources, which can be expensive and technically difficult [46].

In addition, there are environmental problems related to the generation of geothermal energy, such as the possibility of induced seismicity, subsidence, and the emission of volatile compounds and trace gases from geothermal fluids. For these hazards to be reduced, geothermal operations must be properly managed and monitored [47].

Geothermal energy has several benefits despite these drawbacks. It is a base load power source that produces energy continuously, dependably, and with little emissions of greenhouse gases. When combined with other renewable energy sources, geothermal power plants may create a stable and sustainable energy mix while occupying less land than conventional energy producing methods [48]. Furthermore, by using geothermal energy for direct heating and cooling applications including district heating, greenhouse heating, and spa resorts, energy security and resilience may be achieved while lowering dependency on fossil fuels [49].

# 7. Biomass Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

A renewable energy source, biomass energy is produced from organic resources including wood, agricultural waste, and organic leftovers. It is a flexible and easily accessible energy source that may be used to generate power, heat, and fuel for vehicles.

The most common methods for using biomass energy are gasification, anaerobic digestion, and combustion. Biomass is burned in combustion systems to create heat, which may either be utilised directly for heating or transformed into electricity using internal combustion engines or steam turbines [50]. Gasification is the process of heating biomass to high temperatures in a low-oxygen atmosphere in order to create syngas, which may then be transformed into liquid fuels like ethanol or biodiesel or used to generate electricity [51]. Through the process of anaerobic digestion, organic materials are broken down by bacteria in the absence of oxygen, creating biogas-a combination of carbon dioxide and methane-which may be utilised as fuel for cars, heaters, or power plants [52].

The sustainability of biomass production and harvesting, as well as its influence on the environment, is one of the primary difficulties facing biomass energy. Deforestation, monoculture farming, and changes in land use are examples of unsustainable activities that can result in habitat destruction, soil erosion, and biodiversity loss. Furthermore, burning biomass can produce air pollutants and respiratory illnesses by releasing volatile organic compounds, nitrogen oxides, and particle matter [53].

But biomass energy also has a number of benefits. Because the carbon dioxide collected by plants during photosynthesis balances the carbon dioxide released during burning, it is a low-carbon or carbon-neutral alternative to fossil fuels. By producing and processing biomass, biomass energy may also assist lessen reliance on foreign fuels and provide rural areas access to the economy [54].

Additionally, biomass energy may be combined with other renewable energy sources, like solar and wind, to provide a steady and dependable energy source.

Biomass power plants can provide dispatchable electricity generation to complement intermittent renewables, helping to balance supply and demand on the grid [55].

Biomass energy may be utilised not just to generate power but also to produce biofuels for transportation, as well as for heating and cooling purposes. In addition to helping to satisfy energy demands, it may also be used to promote rural development and mitigate climate change due to its capacity to adjust and potential for sustainable production.

# 8. Ocean Thermal Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

Ocean thermal energy, or OTE, is a renewable energy source that produces power by using the temperature differential between the ocean's deep and top waters. It is predicated on the idea that solar energy acquired from sunlight is stored in ocean waters.

OTE power stations are the most popular way to use ocean thermal energy. These plants usually use a closed-loop system to transport heat from warm surface water to cold deep water. The working fluid used in this system is usually ammonia, which has a low boiling point. The working fluid vaporises due to the heat, turning a generator-connected turbine and generating power. The cycle is finally finished when the vapour is condensed back into a liquid using cold water from the ocean's depths [56].

The three primary categories of OTE technologies are hybrid, open-cycle, and closed-cycle systems. As previously mentioned, working fluids are used in closed-cycle systems to transfer heat. In contrast, open-cycle systems use saltwater evaporation directly to power a turbine, whilst hybrid systems optimise efficiency by combining aspects of both closed and open cycles [57].

Despite its potential, ocean thermal energy faces several challenges. The primary obstacle is the very small temperature differential between surface and deep seas, which restricts OTE system performance and necessitates extensive infrastructure for realistic implementation. Additionally, OTE plants can have significant environmental impacts, including disturbance of marine ecosystems and potential interference with ocean currents and nutrient cycles [58].

Ocean thermal energy, however, has a number of benefits. Because of the long-term stability of the temperature differential between surface and deep waters, it provides a reliable and steady source of renewable energy. OTE plants can also offer other advantages like air cooling for coastal regions and desalinating saltwater [59].

Additionally, OTE can support energy independence and security, particularly for coastal regions and island nations with restricted access to conventional energy sources. With continued study and technical developments, OTE may contribute significantly to the shift to a more sustainable energy source in the future.

# 9. Tidal Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

Ocean tides rise and fall on a regular basis due to the gravitational pull of the sun, moon, and Earth. This energy source is known as tidal energy. It is a consistent and dependable energy source that may be used to produce power.

Typically, tidal power plants are used to collect the kinetic energy of flowing water during the tides' ebb and flow. These facilities employ a variety of technologies. Installed on the seafloor in regions with high tidal currents, tidal turbines are a frequent technique. They resemble underwater wind turbines. Through linked generators, the flowing water rotates the turbines when the tide comes in and goes out, producing energy [60]. Tidal barrages, which are substantial dams constructed across estuaries or tidal rivers, are another method of harnessing the power of the tides. Water can enter or exit the estuary through sluice gates built into these barrages during the tidal cycle. Water passing over the barrage powers turbines that are linked to generators, generating energy [61].

Challenges associated with tidal energy include high construction and maintenance costs, as well as potential environmental impacts such as habitat disruption and alteration of sediment transport. Tidal power plants can also have limited deployment locations due to specific requirements for strong tidal currents and suitable geography [62].

Tidal energy has a number of benefits. Tidal energy is a dependable and constant renewable energy source because the tides follow regular and consistent patterns. Once built, tidal power plants have a long lifespan and low running costs, which makes them an affordable choice for long-term energy production [63].

Tidal energy may also aid in lowering greenhouse gas emissions and reducing reliance on fossil fuels, which can help with energy security and climate change mitigation. In addition, tidal power plants can assist nearby communities by protecting against flooding, enhancing navigation, and offering recreational possibilities [64].

Tidal energy is not just useful for producing power; it may also be utilised for desalination, water pumping, and aquaculture. It is a viable solution for supplying energy demands while reducing environmental effects because to its flexibility and resilience.

# 10. Wave Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

Ocean waves contain kinetic energy that may be converted into renewable energy in the form of wave energy. It is a potentially useful resource that is yet mostly unexplored that might add to the world's energy mix.

Technologies aimed at capturing the motion of ocean waves and transforming them into electrical energy are used to harness wave energy. Oscillating water columns (OWCs) are a popular technique that include leaving a partially submerged chamber exposed to the sea. Waves that enter the chamber compress the air within, causing oscillations that power a turbine that is linked to a generator to produce energy [65]. The point absorber, a buoyant apparatus attached to the seafloor, is another method utilised to capture wave energy. A mechanical or hydraulic system that turns motion into electricity is powered by the buoy's up-and-down motion when waves pass by [66].

Challenges associated with wave energy include the harsh marine environment, which can damage or degrade wave energy devices over time. Additionally, wave energy technologies must be able to withstand extreme weather conditions and ocean forces, requiring robust engineering and materials [67].

Wave energy, however, has a number of benefits. The steady and regular patterns of ocean waves make it a dependable and predictable renewable energy source. Wave energy devices can be deployed offshore, reducing visual and environmental impacts on coastal areas [68].

Moreover, wave energy may generate substantial amounts of power, especially in areas with strong and regular wave conditions. It can also help reduce greenhouse gas emissions and dependence on fossil fuels, contributing to climate change mitigation and energy security [69].

Wave energy is not only useful for creating power, but it may also be utilised for desalination, water pumping, and offshore aquaculture. It is an acceptable option for addressing energy demands while avoiding negative environmental impacts because to its versatility and longevity.

# Hydrogen Energy: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

A flexible and clean energy source, hydrogen may be created from a variety of sources and applied to a wide range of tasks, such as industrial operations, power production, and transportation. The main method for obtaining hydrogen energy is electrolysis, which is the process of utilising electricity to split molecules of water ( $H_2O$ ) into hydrogen ( $H_2$ ) and oxygen ( $O_2$ ). Green hydrogen with no carbon emissions may be produced by electrolysis using renewable energy sources including solar, wind, and hydroelectric power [70].

Steam methane reforming (SMR) is a further technique for producing hydrogen. It entails combining methane (CH4) with steam (H2O) at high temperatures to generate carbon dioxide (CO2) and hydrogen gas. SMR is now the most widely used technique for producing hydrogen, however unless it is used in conjunction with carbon capture and storage (CCS) technologies, it is not carbon-neutral and increases greenhouse gas emissions [71]. Fuel cells are one type of technology related to hydrogen energy; they use an electrochemical reaction with oxygen to directly turn hydrogen gas into power. Fuel cells are perfect for powering homes, cars, and portable devices since they are extremely efficient and emit no pollution [72].

Challenges associated with hydrogen energy include the high cost of production, storage, and distribution infrastructure, as well as the need for advancements in hydrogen storage and transportation technologies. Additionally, hydrogen production from fossil fuels raises concerns about carbon emissions and the environmental impact of extracting and processing natural gas [73].

However, hydrogen energy offers several advantages. It is a versatile and scalable energy carrier that can be produced and used in various forms, including gaseous hydrogen, liquid hydrogen, and hydrogen-rich compounds such as ammonia. Hydrogen can be stored for long periods and transported over long distances, making it suitable for grid balancing, energy storage, and backup power generation [74].

Furthermore, hydrogen energy can help decarbonize sectors such as transportation and industry, where electrification may be challenging or impractical. Hydrogen fuel cells can provide zero-emission power for electric vehicles, heavy-duty trucks, and buses, reducing dependence on fossil fuels and improving air quality in urban areas [75].

Hydrogen energy may be utilised for stationary power generation, heating, and industrial activities including the manufacturing of ammonia and steel, in addition to transportation. Its versatility and potential for sustainable production make it a valuable resource for transitioning to a low-carbon energy future.

# 12. Fuel Cell: Basics, Technology, Challenges, Advantages, Disadvantages, Applications

As an environmentally friendly and effective substitute for conventional combustion-based power generating technologies, fuel cells are electrochemical devices that directly transform a fuel's chemical energy into electrical energy. In essence, a fuel cell generates heat, water, and electricity as by-products of reacting hydrogen fuel with atmospheric oxygen. An electrolyte, an anode, and a cathode are a fuel cell's fundamental parts. Fuel made of hydrogen is delivered to the anode, where an electrochemical process splits it into protons (H+) and electrons (e-). While the electrons flow through an external circuit to produce electricity, the protons go through the electrolyte to the cathode. Heat and water are produced at the cathode by the reaction of protons, electrons, and ambient oxygen [76].

Proton exchange membrane fuel cells (PEMFCs), solid oxide fuel cells (SOFCs), phosphoric acid fuel cells (PAFCs), alkaline fuel cells (AFCs), and molten carbonate fuel cells (MCFCs) are among the several types of fuel cells.

Each type of fuel cell operates at different temperatures and uses different electrolytes and catalysts to facilitate the electrochemical reactions [77].

Fuel cell challenges include poor durability and dependability, as well as high costs for materials, production, and infrastructure. Additionally, the widespread adoption of fuel cells requires advancements in hydrogen production, storage, and distribution infrastructure, as well as improvements in fuel cell efficiency and performance [78].

However, fuel cells offer several advantages. They are highly efficient, with conversion efficiencies exceeding those of internal combustion engines and traditional power plants. Fuel cells produce zero emissions at the point of use, reducing air pollution and greenhouse gas emissions, especially when powered by hydrogen produced from renewable sources [79].

Furthermore, fuel cells operate silently and have low maintenance requirements, making them suitable for a wide range of applications, including transportation, stationary power generation, and portable electronics. Fuel cell vehicles offer long driving ranges and fast refuelling times, making them competitive with conventional vehicles powered by internal combustion engines [80].

In addition to transportation, fuel cells can be used for backup power generation, combined heat and power (CHP) systems, and off-grid applications in remote or isolated locations. Their versatility and scalability make them a promising technology for transitioning to a more sustainable and resilient energy future.

# 13. Comparison of Various Renewable Energy Sources is presented in Table 2

Energy Source	Description	Advantages	Disadvantages
Solar Energy	Energy from the sun cap-	Abundant, sustainable, low	Intermittent, high initial cost,
	tured via panels or mirrors	operational cost	requires large areas
Wind Energy	Energy from wind captured by turbines	Clean, cost-effective, scalable	Intermittent, noise, visual impact, impact on wildlife
Hydro Energy	Energy from moving water	Reliable, flexible, can generate large amounts of power	Environmental impact, displace- ment of communities, costly
Geothermal	Heat energy from within	Reliable, small land footprint,	Location-specific, high initial
Energy	the Earth	low emissions	cost, risk of earthquakes
Biomass Energy	Energy from organic	Reduces waste, carbon neutral	Emits greenhouse gases, requires
	materials	(if managed sustainably)	large land areas
Ocean Thermal	Energy from temperature	Consistent, vast resource	High cost, environmental impact
Energy	differences in ocean water	potential	on marine ecosystems
Tidal Energy	Energy from tidal forces	Predictable, long lifespan of	High cost, limited suitable sites,
		installations	environmental impact
Wave Energy	Energy from surface waves	Predictable, large energy	High cost, environmental impact,
		potential	technological immaturity
Hydrogen Energy	Energy from hydrogen used	High energy density, clean if	High cost, storage and transport
	in fuel cells	produced renewably	challenges
Fuel Cell	Device converting hydrogen	High efficiency, low emissions	High cost, hydrogen production
	into electricity		and storage issues

Table 2: Comparison of Various Renewable Energy Sources

# 14. Conclusion

In conclusion, this paper has explored various renewable energy sources as solutions to the future energy crisis. The investigation highlights the potential of various renewables as already mentioned earlier to provide sustainable, clean, and efficient alternatives to fossil fuels. While each source has its individual strengths and limitations, collectively they offer a viable path to reducing greenhouse gas emissions, enhancing energy security, and fostering economic development. Overcoming obstacles such as intermittency, higher costs required in initial stages, and the requirement for improved framework and installation will be crucial. Nonetheless, the transition to renewable energy is essential for a sustainable and resilient energy future.

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# 51. A thorough investigation on hybrid renewable energy system management techniques

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#### Abstract

Using all available energy sources is essential to meeting the growing demand for energy. The intermittent nature of renewable energy sources is a disadvantage, despite the fact that they are plentiful, clean, and pollution-free. To address this problem, a hybrid energy system that incorporates renewable energies is used. This study presents and analyses comprehensive assessments of recently published studies on hybrid renewable energy. This study presents its conclusions after reviewing hybrid renewable energy system management techniques.

Keywords: Hybrid renewable energy system (HRES), Management methods, Technical objective strategy, Economic objective strategy, Techno-economic objective strategy

#### 1. Introduction

Solar energy is the most affordable way for our nation to meet its projected energy needs. As costs come down, consumers in India are becoming more interested in solar energy [1]. Almost every city in our nation had very few solar installations before 2015. To meet the demand for electricity in the future, better hybrid PV plants are extremely necessary. The best mixed photovoltaic systems for a smart city may be chosen using the research's consideration of specialist displays, environmental issues, and financial considerations [2, 26]. One of the most affordable and reliable grid options for powering rural customers is HRES due to the fact that they mitigate climate change by lowering the consumption of fossil fuels [3]. HRES has several advantages over systems based on a single energy source, including greater reliability, higher efficiency, modularity, the requirement for less energy storage capacity, and a lower LCOE [4,5]. The development of the corona virus and the total blackout result in a 5.9% decrease in worldwide energy consumption in 2020 compared to 2019. Global economic progress led to

a notable 3.8% global drop in power demand in the first quarter of 2020 compared to the same time in 2019 [6]. In 2020, the demand for renewable energy has increased by 1.5 percent in the first four months, increased output of solar and wind power from newly constructed facilities in the preceding year. Green energy sources are frequently prioritised by the grid because they are not subject to demand-side adjustments, which protects them from the impact of the reduction in energy use [7]. Exxon Mobil's most current energy forecast states that by 2040, nuclear and renewable energy sources will account for 25% of the world's electricity consumption [8]. Algeria has one of the best solar energy systems in the world, receiving 2000 hours of solar radiation throughout the entire country and 3900 hours over the Sahara and highlands. Algeria experiences  $3 \times 10^3$  Wh/m<sup>2</sup> global horizontal radiation in the north and above  $5 \times 10^3$  Wh/m<sup>2</sup> in the south (Sahara). Algeria possesses a noteworthy wind resource as well, with wind velocities ranging from 4 to 8 metres per second. Indeed, it's predicted that the south of the region would generate 35 TWh a year from its wind energy resources [9]. Algeria, the 131st-ranked country in the world, is the newest to use green energy internationally, accounting for 1.5% of global electrical output [10]. In contrast, the government's 2011–2030 renewable energy plan stipulates that a plan must be put in place to meet the 22,000 MW of national market demand between 2015 and 2030 [11].

Hybrid renewable energy systems (HRES), which blend multiple energy sources with one renewable energy source, include electrical systems. It is possible to employ conventional, sustainable, or a mix of these sources, and the system may run off-grid or on-grid [12]. It has been shown that the selection of various device elements for the mixed energy plant may be dependent on several size characteristics. A number of commercial software are also used for the size and optimisation; most of these programmes utilise Windows as a basis for the visual C++ programming language. Software such as INSEL, RETScreen, iHOGA, and HOMER are examples of this kind. If the development of an HRES project is disorganised and inadequately planned, the investment costs may exceed initial projections [14]. Diverse modelling and analytical techniques, along with simulation tools, have been employed to assist mixed system users with their planning, research, and development efforts. In real life, simulating mixed systems requires interacting with expressions that specify the organisational framework for different HRES components. Consequently, the system's conduct may be shown, which might aid in project decision-making [15]. Using user-provided data, such as climatic parameters and size parameter spectrum, the simulating programmes generate non-identical versions of green energy systems [16, 17]. The various simulation approaches' non-identical combinations may be explained by their intrinsically distinct dispatch algorithms [18]. A method that has been shown to work well in light of the system's components, the local geography, and the meteorological data must be used to optimise the performance of the hybrid energy system [19].Figures 1(a) and 1(b) depict the variables that comprise a relevant HRES system and the optimisation procedure, respectively. No matter how complex a mixed energy system project is, for improved comprehension, analysis, layout, and planning, a thorough theoretical pre-feasibility analysis and a meticulous review of the veracity of its results using a highly specialised simulation tool and pertinent and significant circumstances used as specific instance studies are necessary [16]. Consequently, a comprehensive HRES research is essential for effective RES utilisation and precise project design [20]. An ideal sizing process is required to economically and efficiently utilise renewable energy sources.

By optimising the use of photovoltaic, wind turbine, and storage batteries, the optimal size strategy may help achieve the lowest feasible cost while enabling the mixed structure to operate at the highest levels of dependability and economy. Finding the best balance between cost and durability may be possible if pricing targets are defined and system functioning is taken into consideration [22]. An HRES is a type of electrical system that integrates many renewable energy sources into one unit. The system is able to function both on and off the grid, using conventional, renewable, or hybrid energy sources [23]. It has been found that a wide range of commercial software tools, including as iHOGA, PVSOL, HOMER, RETScreen, PVSyst, INSEL, TRNSYS, and others, are useful for sizing and optimising HRES [24]. Figure 2 displays the total number of publications for the mixed system from 1992 to 2022, varying according to various configurations.



Figure 1(a): A HRES system formation [27]



Figure 1(b): Optimization methodology in HRES [27]



Figure 2: The number of articles for mixed system from 1992-2022 depending on different arrangements [27]

Many green energy efforts energise rural regions and provide the global area (buildings,

industry, and residential sector) with energy. This section will concentrate on the HRES energy consumption profile that is most frequently utilised. An island, a mountain, a small village in the desert, or a few off-grid homes are examples of an isolated area kind of load; the type of habitation sector depends on the country of residence and the quantity of linked devices. Due to financial and technological limitations, industry is seldom ever studied by scientists in their research. Examples of these limitations include the need for a large area, the need for continuous energy generation, the quality of energy, and the requirement for a significant investment. Building is ascribed to grid connectivity, transportation accessibility, low energy use (a few kilowatts), etc. It might be a government office, a market, an institution, a lab, a school, etc. [25].

# 2. Management Methods of HRES

In order to increase performance of the system, management of the mixed system guarantees maximum efficacy of the system and maximum dependence at the lowest feasible price to allow all the year system supply [30], a decline in the financial variable, and an upliftment in the element lifecycle.



Figure 3: Various Management Methodologies [29]

These are divided into 3 types as follows (Figure 5) [31]-

- Technical objective strategy
- Economic objective strategy
- Techno-economic objective strategy

# 2.1 Technical Objective Strategy

Primary aim of the approach here is - to consider technological variables of mixed arrangement for satisfying need for load [32,33], boost device longevity [34], perform better [35], boost system's stability [36], elevate life span of storage system, & other various variables describing each generator of the mixed arrangement (Figure 4). Different techniques, such as PSO [39], neural networks [41], realtime optimization [40], predictive control [38], and HOMER-software [42], are used to regulate these parameters.



**Figure 4:** Major Features of Technical Objectives Strategies [29]

### 2.2 Economic Objective Strategy

Whatever the condition of the technology of the system, an economic objective strategy is any plan that takes into consideration some factors impacting the system's monetary condition. (Figure 5) [31]. Two primary aims—meeting of requirements and system's price decline are included in the most important economic strategy studies that have been published. These objectives are achieved using a variety of algorithms, including model predictive control [38], generic algorithm [43], mixed integer linear programming [45], differential evolution algorithm [44], interior search algorithm [47], fuzzy logic [46], and commercial software like HOMER-software [48].



Figure 5: Prime Attributes of Economic Objectives Strategies [29]

#### 2.3 Techno-economic Objective Strategy

The approach explained here, which incorporates both technical and economic elements, is built on optimization that is not linear to find solution to multi-objective functions. The benefit of this method is that it lowers



Figure 6: Primary traits of Techno-Economic Objectives Strategies [29]

economic parameters like global cost while increasing technical characteristics like component performance and lifetime (Figure 6) [49]. The primary techniques employed here depends on PSO [51] & fuzzy [50]. Anyway, this strategy also employs numerous additional techniques, including artificial electric field algorithms [53], flowcharts [52], and HOMER-software [54].

# 3. Management Methods Review

A brief review on various management techniques for implementation of hybrid renewable energy resources is depicted in Table 1

System Components	Optimization Objective	Algorithm Uses
Technical Objective		
Photo Voltaic / Diesel Generator / Wind Turbine/Battery	Verify requirement Boost the use of green energy sources	Receding Horizon Optimization
Photo Voltaic / Wind Turbine /Fuel Cell/Battery	Verify requirement Boost system dependability	Predictive Control
Photo Voltaic / Wind Turbine / Diesel Generator /Battery	Verify water & electrical need Increase green energy resources	HOMER
Photo Voltaic/ Diesel Generator	Maintain security of the system Minimization of the losses of the system	Second-Order Cone Programming
Photo Voltaic / Wind Turbine / Battery/Utility Grid	Increase the usage of green energy Lengthen lifespan	Closed Feedback Loop
Photo Voltaic / Wind Turbine / Battery/Utility Grid	Verify water & electrical need Decrease the power supply probability's potential loss	Neural Network
Direct current renewable resources/ Utility Grid Photo Voltaic/Battery	Verify requirement Creating independent micro grids	Direct-Current Electric Springs
Photo Voltaic / Wind Turbine / Utility Grid	Verify requirement Verify the service quality	Real-Time Optimization
Photo Voltaic /Battery	Remove excessive outputs and charging too much Robust control	Power Flow
Photo Voltaic / Wind Turbine / Fuel Cell /Battery	Minimization of Power Supply Probability Loss Increase Factor of Safety	Particle Swarm Optimization
Economic Objective		
Photo Voltaic / Wind Turbine / Fuel Cell /Battery	Verify requirements Decrease of price	Fuzzy Logic
Photo Voltaic / Wind Turbine / Diesel Generator Battery/Hydropower	Minimization of levelized price	HOMER
Photo Voltaic / Wind Turbine / Utility Grid	Minimization of price of operation	Generic Algorithm

 Table 1: Management methods review [33-54]

(Continued)

Fuel Cell /Battery/Utility Grid	Decrease the price of energy	Mixed-Integer
Table 1: (Continued)		Linear Programming
System Components	Optimization Objective	Algorithm Uses
Photo Voltaic / Wind Turbine	Minimization of the entire price charge	Differential Evolution Algorithm
Photo Voltaic / Wind Turbine / Fuel Cell	Verify requirements Decrease of price	Interior Search Algorithm
Photo Voltaic / Wind Turbine / Fuel Cell /Battery	Decline of the price of operation & price of the investment	Model Predictive Control
Techno-Economic Objective		
Photo Voltaic / Wind Turbine / Fuel Cell /Battery	Verify requirements Decrease of price Lengthen lifespan Improve execution	Flow Chart
Photo Voltaic / Diesel Generator /Battery	Verifies a dependable supply of power Increase lifespan of battery Minimization of the electricity's price & net present price	HOMER
Photo Voltaic / Wind Turbine	Decline in the losses of line Increase dependability Decrease price related to loss & increase price of saving	Fuzzy Logic
Photo Voltaic / Wind Turbine / Diesel Generator /Battery	Verify requirements Decrease of price Lengthen lifespan	Artificial Electric Field Algorithm
Photo Voltaic / Wind Turbine / Fuel Cell /Battery	Verify requirements Decrease of price Lengthen lifespan Improve execution	Particle Swarm Optimization

# 4. Conclusion

To fulfill the growing need for energy, all available energy sources must be used. The intermittent nature of renewable energy sources is a drawback, despite its abundance, cleanliness, and lack of pollution. A hybrid energy system that integrates renewable energies is utilized to overcome this problem. Comprehensive evaluations of newly released research on hybrid renewable energy are presented and analyzed in this work. This essay looks at a number of hybrid renewable energy system management solutions and reviews the several management methods used in HRES.

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# 52. Review of the growth prospects for renewable energy in several countries

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#### Abstract

The use of renewable energy is now crucial to addressing environmental issues. The advancement in this area has the potential to increase energy efficiency and lessen the greenhouse effect. This essay highlights the state of renewable energy development in several nations. Analysis has been done of the rising renewable energy development trend. The energy market must be changed, and the rationality of policymaking must be maintained, in order to support the development of renewable energy sources. The energy industry benefits from a good educational system and awareness of renewable energy in the event of development. This study revealed that a significant amount of research is being done on renewable energy. This essay has informed readers about numerous uses for renewable energy as well as how those uses have changed across different countries.

Keywords: Renewable Energy, Solar energy, Wind energy, Hydro energy, coal energy, nuclear energy, natural gas, Geothermal energy, Biomass energy, international development.

#### 1. Introduction

Energy efficiency improvements and greenhouse gas reduction are challenging tasks in the modern world [1, 2]. The best alternative solution to this issue is renewable energy. Additionally, it significantly contributes to raising employment levels across nations and enhancing environmental preservation. For the creation of the next generation of energy technologies, many nations used renewable energy [3, 4]. Experience in low-carbon development is crucial as national policies develop and renewable energy technologies enter their middle age. [5]. Numerous studies have examined how renewable energy is developing. Pazheri et al. [6] assessed the state of renewable energy and discussed the most recent developments in bringing down the price of renewable energy. [7]. The development of renewable energy was explored by Zhang et al. [8] together with China's energy structure. Increases in the capacity of renewable energy sources and the proportion of electricity used for energy consumption are both required to reduce carbon emissions. Wang et al. predicted China's condition of sustainable energy development and examined energy-saving policies [9]. Even though several studies on various forms of renewable energy have already been conducted, there are very few systematic comparisons and analyses of these studies in the literature. Furthermore, they could contain partial statistics or missing data; as a result, it's important to undertake a thorough and systematic examination of global renewable energy using study findings made public by reputable institutes.

## 2. Development State of Renewable Energy

According to statistics, even though the amount of primary energy consumed globally has decreased yearly, throughout the last two years the pace of global energy consumption has been steadily increasing. Similar to this, the growth in fossil fuel usage over the last ten years has only totaled 16.90% [10,15]. Coal consumption is continuing to decline at a lower rate. Comparing the data from 2017, for instance, we can see that the growth rate was only responsible for around one-third of the increase in primary energy use The total amount of nuclear energy used worldwide has been steadily declining due to safety concerns. When compared to the level from ten years ago, nuclear power usage has been steadily declining for two years [11]. On the other hand, the use of natural gas is also growing quickly during the past three years and will reach its peak in ten years. Other renewable energy sources had growth at a rate of up to 16.64%, or approximately The consumption of fossil energy is growing at a rate that is 11 times faster than average [12]. Various renewable energy sources, including wind, solar, biomass, geothermal, hydrogen energy, and other sources, have different development structures depending on the country. There is still a lot of space for development in China's renewable energy [13].

# 2.1 Renewable Energy Evolution in European Union

In the European Union, the energy revolution began much earlier. The biggest carbon emissions trading scheme in the world was originally introduced in 2003, and it also produced impressive results. They have policies and goals for short-, medium-, and long-term development as well as support mechanisms and sustainability requirements. EU Leads the World in Energy Structural Transformation. They consume 2.5 times as much coal, nuclear, and non-hydro renewable energy than the typical country worldwide [13]. In 2030, renewable energy generation in the EU is predicted to increase by 50% compared to the current scenario, according to various reports [14,15]. Electricity demand has increased along with energy efficiency. The EU will likely need to make additional efforts to meet its renewable energy objective, according to the current scenario [16].

# 2.2 Renewable Energy Evolution in US, Australia, and Brazil

Australia now ranks tenth in the world in terms of energy production, and it is one of the three OECD countries that export energy on a net basis. However, the overall energy structure is still being developed, and the share of renewable energy is rather marginal [19]. Brazil is a global leader in the usage of renewable energy. Brazil was the first nation to use biomass fuels, and it is also the greatest producer and consumer of this fuel. energy usage ongoing expansion and an increase in the proportion of renewable energy. Brazil, which ranks seventh in the world for installed capacity, has significant wind energy potential. Brazil, which became a pioneer in liquid biofuels, was likewise committed to creating alternative fuels [15]. The United States becomes the world's leading producer and exporter of wood pellets and biomass power

in this situation. The state of renewable energy development is favourable. According to the EIA research, industry will consume much more energy and electricity, and correspondingly, the rate at which renewable energy is consumed will also continue to rise [15].

#### 2.3 Renewable Energy Evolution in India

The second-most populous nation in the world is India. Here, there is a clear imbalance between the supply and demand of energy, and there is also a high need for renewable energy. India experiences energy shortages, external energy reliance, and energy security challenges, all of which are progressively becoming more important as a result of economic expansion and energy consumption. Since the demand for renewable energy is always rising, the supply must also rise in line with this trend. While coal has long been above 50% of India's energy mix, fossil fuels continue to hold the absolute top spot. Compared to the corresponding consumption rate, less coal, oil, and natural gas have been produced. It is necessary to preserve India's rapid development as a result of renewable energy Renewable energy is developing quickly and has a lot of potential. India is the seventh-largest hydropower producer, with a big hydropower installed capacity of 45.29 GW in 2017 [17–19], according to the sources. India has abundant biomass resources thanks to its favorable geography. The research states that in 2017, 8.4 GW of electricity were produced by biomass generating, gasification, and combined heat and power In India, however, there is not enough of a spread of renewable energy. On the

other hand, given the quick rise in global energy consumption, renewable energy production needs to be bolstered in comparison to traditional energy, which is still growing significantly [20]. In 2050, India will produce 75% of its energy from renewable sources, according to a prediction by Bloomberg New Energy Finance (BNEF)

## 3. Conclusions

The demand for renewable energy in many parts of the world has been established by the current study, and it has led to a development of these sources. The rate of the EU's use of renewable energy is quite high, and the sector's growth is enormous, as are overall reductions in greenhouse gas emissions. In contrast to the utilization of wind energy, India's biogas industry is expanding. The rise of renewable energy is also being seen in Australia and the USA. To meet the targets and boost the capacity of renewable energy sources for absorption, longterm learning from international experience will be required. To improve the power system, it is necessary to boost renewable energy's capacity for absorption by optimizing the use of currently existing resources.

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# 53. Energizing smart grid

An in-depth analysis of energy storage technology and applications with integration of renewable energy

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#### Abstract

The problem of inadequate transmission line margin in the transmission network is becoming more and more evident as a result of the availability of distributed generation (DG) and demand side resources (DSR) resources. This opens up new opportunities for the active distribution network (ADN) to support the transmission network by providing auxiliary services.

Keywords: transmission congestion management, active distribution network, coordinated scheduling, active reconfiguration, active islanding

# 1. Feasibility of ADN Participating IN

Many academics domestically and internationally have looked into how DGs and DSRs participate in the management of transmission congestion [1–6]. ADN is more intimately related to the transmission network since it serves as the active control and management centre for these resources, making it possible for ADN to take part in the management of transmission congestion [11], [7–10].

At the level of the transmission network, congestion management has been implemented using the controllable distributed resources and DSRs in ADN. Controlling the active and reactive power injection of DGs and flexible loads to meet the specified value of TSO in order to [1] support the functioning of the transmission system forces the behaviour of the power grid to alter. The effects of the best positioning and sizing of dispersed resources on transmission congestion are studied in references [2] through [4]. Introduce energy storage, electric vehicles, and other demand response resources as tools for reducing transmission congestion in references [5–6]. In conclusion, ADN participation in the coordinated scheduling for transmission and distribution is emerging as a new option for managing transmission congestion. According to Figure 1, there are primarily two ways for ADN to participate in the management of transmission congestion; as a result, this paper reviews these two approaches and combines them with the most recent research on active reconfiguration and active islanding of ADN both domestically and internationally.

ADN's participation in the control of transmission congestion is prospected at the conclusion of this study, along with future development and research directions.

## 2. ADN Rescheduling yo Participate IN

#### Transmission Congestion Management

Rescheduling is mostly used in classical transmission congestion management to minimise the power flow of overload lines [12]. Similar to this, ADN can use scheduling to take part in coordinated transmission and distribution congestion control.

The scheduling outcomes of the transmission and distribution networks will interact as ADN eventually gains more scheduling autonomy. As a result, when developing a scheduling strategy for the transmission system, coordination between the distribution network and the transmission network should also be taken into account. In addition to using standard units and dispersed resources at the transmission network level, when transmission congestion occurs, controlled and Additionally, variable resources within ADN can be used for cooperative "rescheduling" to reduce transmission congestion. As a result, the transmission and distribution coordinated economic dispatching serves as the foundation for ADN's participation in transmission congestion management.



Figure 1. Ways of ADN participating in transmission congestion management

#### 2.1 Transmission and Distribution Coordinated Economic Dispatching with ADN

The modelling and computation of coordinated economic scheduling is the main focus of research on transmission and distribution coordinated economic dispatching. ADN and its internal controlled resources are typically seen as a node in the transmission network connecting an equivalent generator and an equivalent load, or as ADN as a whole [13]. To create coordinated control between ADN and the transmission network, the generalised bidding function [14] and external regulating margin are applied.

There are many similarities in terms of modelling, the differences between various transmission and distribution coordinated optimal models are: (1) whether AC optimal power flow or DC optimal power flow is adopted for transmission network and distribution network; (2) differences of ADN's model caused by differences of inner controllable distributed resources and flexible loads.[15]

Although different transmission and distribution coordinated optimal models share many modelling characteristics, there are some key differences. These include: (1) whether AC or DC optimal power flow is used for the transmission and distribution networks; and (2) differences in the ADN model due to variations in internal distributed controllable resources and flexible loads. [16]

To resolve the transmission and distribution coordinated scheduling model, Lin C et al. [16] use a novel decentralised approach called multi parameter quadratic programming. The final model is solved by iterations according to C Shao et al.'s [11] use of Benders decomposition algorithm, which transforms a two-level optimum problem into a hierarchical optimal problem. By using KKT conditions, Y Jin et al. [8] reduce a double-layer AC power flow coordinated scheduling model to a single-layer model, which is subsequently solved.

The transmission and distribution networks are simulated independently in common, despite the fact that the various algorithms listed above are based on several different models. The coordinated model is transformed into a hierarchical optimal problem by each of the aforementioned methods, which is then resolved using iterations or KKT conditions. While KKT conditions can prevent falling into the local optimum when the optimal model of the lower layer is convex, iterative algorithms are more likely to do so because the scheduling results of the upper layer should be passed to the lower layer as constraints.

#### 2.2 Transmission and Distribution Coordinated Rescheduling in Congestion Management considering ADN

ADN's participation in transmission congestion management differs from traditional demand response resources' participation in congestion management in that the DSO operator controls DG output in ADN to reduce congestion at the level of the transmission network rather than load reduction, which to some extent ensures user comfort.

In most cases, a coordinated double-layer transmission and distribution management

model is implemented. Reverse power flow relieves congestion in overload lines because the lower layer optimal model's goal is to maximise ADN revenue while the upper layer optimal model's goal can be to minimise total power adjustment [13] or total adjustment costs [7, 17] of resources in the transmission network and DGs in ADN. Congestion management that takes into account ADN will remove congestion with the least amount of scheduling result modification when the goal of the higher layer model is minimization of the total power adjustment. Congestion management taking into account ADN will remove congestion with best economy when the goal of the higher layer model is minimising the total adjustment costs.

The internal operation safety of ADN is disregarded in studies using its rescheduling behaviour to relieve transmission congestion and solely concentrates on the operational safety of the transmission network. Although there is no longer any congestion at the transmission network level, there may still be some local congestion within ADN. ADN will change the output of the DG to address the local congestion, which will have an impact on the transmission network's rescheduling outcomes.

The access position of ADN will affect the effect of congestion management [17]. The price of DGs in ADN is generally higher than conventional generators in transmission network, ADN should be connected to nodes that are close to loads but away from generators in order to be called more often. If not, it will be more inclined to employ relatively cheaper conventional generators in transmission network when the optimal objective is minimizing the adjustment costs, in which ADN's participation will increase the adjustment burden of conventional generators in transmission network.

# 3. Adjusting ADN'S Network Topology to Participate IN Transmission Congestion Management

ADN can optimise its own network topology to provide auxiliary transmission congestion management by active reconfiguration or active islanding with real-time communication with transmission network thanks to the variety of operation modes, internal flexible resources, and development of communication technology.

#### 3.1 ADN Active Reconfiguration to Participate in Transmission Congestion Management

To determine the switch status, network reconfiguration is a combinatorial optimum problem. The two main technical challenges are the radial topology constraint and the network reconfiguration technique [18].

The topic of distribution network reconfiguration is a mixed integer nonlinear programming problem that is more challenging and less effective to address using traditional mathematical procedures [19].

Switch exchange techniques can quickly improve ADN's network topology by changing switch status, but it might be challenging to determine which reconfiguration strategy is the most effective [18]. In contrast, intelligent algorithms, like the evolutionary algorithm [20, 21], are the best for addressing distribution network reconfiguration problems because they are more effective at identifying the global optimal reconfiguration scheme.

The loop method and the spanning tree method are the traditional approaches for addressing ADN radial operating constraints [22, 23]. The first one searches for all independent loops and evaluates each one individually to see if it satisfies the radial operating requirements with just one switch on. And it will run into a lot of impractical solutions. The latter method identifies all spanning trees through a specific strategy, all solutions developed throughout the optimization phase meet the radial operational restrictions. However, it cannot deal with combination explosion of spanning trees [24–31].

In order to improve the processing effectiveness of the radial operational restrictions of ADN, several researchers make use of the encoding properties of intelligent algorithms to rationally choose switches as intelligent particles or decision variables. To determine whether the radial operating restrictions are met during the optimisation process, some approaches aren't even required. The following are the typical processing techniques:

1) This method only allows one switch to be on in a loop and is based on an improved beetle antennae search algorithm. Establish a network loop switch matrix A(aij) with only 0 and 1 values depending on whether particle j is in loop i using the number of switches opened in each ring network as the code for each particle. The point in matrix A(aij) that corresponds to particle j being in loop i is 1. If the rank of matrix A(aij) is fewer than the number of loops, it is then simple and rapid to evaluate whether the particle satisfies the radial and island-free operational constraints.

2) This approach is based on the evolutionary algorithm and spanning trees of undirected graphs. The number of switches in each link branch is taken into account as the basis vector for each spanning tree. One switch is always opened on each link branch at a time, and the number of switches open on each link branch is used as the decision variables to encode in decimal mode.

Consider a streamlined graph (Figure 2) with seven branches numbered from (1) to (7), fifteen switches numbered from 1 to 15, three loops, and three tie switches.

Taking into account the spanning tree's link branch, (3)(5)(6)(7) is [1,5,1], while the base vector is (1)(2)(4). The number of switches on each connection branch is listed in Table 1. Switches 1/11/2 must be open for chromosome to be [0,0,0]. Switches 1/13 and 2 must be open for the chromosome to be [0,2,0]. Every chromosome made falls within the range that is conceivable [24].



Figure 2. Simplified system

Table 1 Number of Switches on Link Branches

 NUMBER OF SWITCHES ON LINK BRANCHES

 switch number
 0
 1
 2
 3
 4

 (1)
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3) The switch status is used as a decision variable in this method, which is based on the binary particle swarm algorithm. To create ring networks, turn off all tie switches first. When only one switch is allowed to be on in a network with a single loop, the network formed undoubtedly operates in radiation. When only one switch among the other switches in a multi-loop network is authorised to be on and only one switch in the common branch is allowed to be open, the network established unquestionably satisfies radial operational constraints [25].

Take Figure 2 as an illustration. If switches 5 and 6 are both turned on, the particle will be in the position [0,0,0,0,1,1,0,0,0,0,0,0,0,0] and is not practicable because switches 5 and 6 are on the same common branch. The position of the particle is [0,0,0,0,1,0,0,0,0,1,0,0] and it is possible if switches 5 and 13 are open.

Every particle produced using this process falls within the practical range.

However, if ADN's participation is meant to reduce congestion, the goal of which should be shifted to minimization of tie-lines' power flow. Domestic scholars conduct research on ADN reconfiguration with the goal of reducing the power flow through tie-lines to relieve the transmission network's pressure [9, 10]. However, during the solving processes, they must both decide whether the redesigned ADN satisfies the radial operating limitations. Therefore, when combined with the approaches discussed above that address radial operational restrictions, ADN's reconfiguration models [9, 10] can help the transmission network handle transmission congestion more effectively and efficiently.

#### 3.2 ADN Active Islanding to Participate in Transmission Congestion Management

The original purpose of islanding was to guarantee power supply in the event of system breakdowns. The active islanding of ADN, which serves as a tool for transmission congestion control, creates an island under normal circumstances with the requirement that all loads within the island range be supplied.

Finding the maximum island range is essential for active islanding. Since there are two n 1 island schemes in a radial network with n nodes, depthfirst search is frequently used to condense the solution space for distribution network islanding. The maximum island range is more frequently determined using a depth-first search from the inner to the outer layer because conventional islanding does not need to supply power for all loads. Operators of the system must decide which nodes to use to supply electricity in accordance with their goals when loads on a particular layer cannot be totally satisfied. The nodes on this tier should be prioritised in ascending order of power if the goal is to maximise customer comfort. Then, nodes from left to right are selected until the sum of these nodes' power reaches the island's remaining power supply capacity [30]. The nodes on this network should be used if the goal is to increase the utilisation of DGs in ADN.

In contrast, ADN active islanding is intended to help the transmission network reduce congestion, and it must be assured that all loads within the island will have access to power. As a result, the maximum island range determination approach is distinct from the above-mentioned standard methods. The top node of the rooted tree is destroyed and moved down one layer to restrict the island range when loads on some nodes cannot be fulfilled. The transmission network's generation resources [9, 10] supply loads to the removed top node. To effectively remove congestion, it is the same as shifting a portion of loads to ADN.

When the power reduction value of a tie-line or the total active power of loads in an active island is less than the gap between the power flow of a congestion branch and its capacity, both methods of topology adjustment cannot completely eliminate congestion. As a result, when these conditions exist, the degree of congestion alleviation by ADN active reconfiguration and active islanding is less than that of ADN rescheduling participating in transmission congestion management.

#### I4. Conclusion

- 1) ADN's contribution in transmission congestion management, which focuses on modelling and algorithms that essentially address how to coordinate the coupling and connection between transmission and distribution networks, is based on transmission and distribution coordinated economic dispatch.
- 2) There are various transmission congestion management application situations for ADN rescheduling and ADN network topology change. ADN reconfiguration may be used

pletely remove congestion. Demand response resources and topology adjustment may be taken into account in transmission congestion management when neither of them is able to completely eliminate transmission congestion. ADN rescheduling combined with demand response resources can be utilised to reduce congestion if none of the three can do so.

ADN participation in transmission congestion management has made some progress in recent years, but there are still areas that need to be strengthened. For instance, it would be worthwhile to conduct more research on how ADN and other market participants allocate the costs of congestion management.

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# 54. A evaluation of the integration of renewable energy sources and electric vehicles in the smart grid

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#### Abstract

Restructuring has accelerated over the past few years across all conceivable sectors, including the power supply industry. Restructuring brings about a lot of significant changes.

Today, electricity is more than just a source of energy; it has also evolved into a deregulated good. To satisfy such a large and continuously increasing demand in a cutthroat market set the standard for numerous participants. The transmission line becomes overloaded and congested as a result. Furthermore, open access transmission networks cause more severe congestion issues. As a result, controlling congestion in power systems is crucial to the functioning of the electricity market. This report examines publications that are linked to the work on congestion management.

Keywords: restructuring; deregulation; commodity; congestion; congestion management; transmission line.

#### 1. Introduction

The power sector has transitioned from regulated to deregulated markets as demand rises and recursions accelerate technological advancement. Early on, there was a monopoly on the electricity power market. Only a sizable utility generally referred to as a vertical integration utility—has the right to generation, transmission, and distribution.

The industry needs to be restructured for this. However, there are numerous difficulties in a deregulated market, such as choosing the best power auction strategy, reducing market participant power to lessen transmission congestion and the resulting location price spikes to maintain the system's reliability, and assessing market efficiency and equilibrium [1]. Congestion management (CM) is the most current and important issue among these difficulties. Power is delivered to the client via a transmission line (TL) in an open energy market. When the transmission network's capacity is less than the demand currently being met by the market, congestion in the TL results. Such issues must be eliminated from the transmission network. As a result, CM is a technique for effectively delivering power within the constraints of the system. CM is a tool that is employed to lessen TL congestion. The two approaches of CM can be broadly divided into the following categories.

- 1. Cost-free Method,
- 2. Costly Method.

The TSOs dominate approaches that are free of charge. When these approaches are used, the network topology, how transformer taps are installed, and how common compensating devices like phase modifiers and flexible AC transmission system (FACTS) devices are used are all altered. These techniques are referred to be free ways due to financial considerations. Therefore, there is no involvement of generation and distribution utilities in these methods. While expensive techniques alter generation, postpone it, and lower load transactions.

Seema and Lakshmi [2] have reviewed many conventional methods of CM. But the topics coverage is limited to price control theme, nodal pricing method, Genetic algorithm (GA) based CM, nodal and zonal congestion, fuzzy logic, voltage stability, CM through FACTS devices and analogy based on market. In [3] a brief discussion has been shown considering the different aspect of contingency. Many optimization techniques have been shown for alleviating the congested problem. So many methodologies for CM has been shown. The key issues and challenges have also been discussed for alleviating congestion problems. This paper reviews the CM problem using technical as well as nontechnical method in different countries.

# 2. Congestion management by conventional methods

#### 2.1 Nodal Pricing Method

According to the location, nodal prices vary throughout the network. Here they are named "location marginal price" (LMP). The nodal price encourages the surplus generation of power. Then the surpluses power is available to pay for "contract rights." Contract holders get rights to input power from a node and take output from another node in the system network [4].

The following four approaches can be used to calculate LMPs. (i) The system was in operation before to and following the 1 MW utilisation. Based on the difference in operating costs, the LMPs are calculated. This strategy is pessimistic and not used in real life. LMP calculation based on marginal generator sensitivity parameters (ii). Each generating unit's cost of producing energy can be determined in this way. (iii) The lagrangian multiplier (LMP) for optimal power flow (OPF) calculation. (iv) The "Transposition of Jacobean Matrix" method, in which the Jacobean matrix's restrictions are used to substitute row and column, can be used to calculate LMP [2]. By introducing several performance measures for comparing alternative scheduling approaches to lower total congestion costs, the author hopes to enhance social welfare result issues. This strategy has been used by the author on systems with 3 and 8 buses.

Using the IEEE30 bus system as an example, Sood, N.P. Padhy, and Gupta proposed a generalised deregulation model in [5]. The concept uses private negotiations, distributed pools, and multilateral agreements to maximise social benefits. The effects of TCSC on the oversaturated power market and deregulated spot prices have been researched and evaluated by Acharya and Mithulananthan. The outcomes achieved in this method contribute to the argument that TCSC can lessen congestion and loss.

A new control strategy was proposed by Jokic, Lazar, and Bosch; it uses the nodal price of the power system for CM and power balancing. The authors also suggested a controller that can detect the boundaries of every line in a stable state and guarantee operational economic stability [6].

A new regional marginal pricing system has been put into place in [7] Kang. The technique is founded on identifying the factors that contribute to congestion and sequential network partitioning that has been tested on an IEEE-39 bus system. For the purpose of analysing single auction model spot prices, lowering fuel costs, and enhancing social welfare, M. Murali employed the DC optimal power-based BAT algorithm stream. It turns out that the BAT method outperforms both linear programming (LP) and genetic algorithms (GA). The LMP takes into account both the marginal and congestion costs. These fees are paid at the appropriate nodes; the congestion cost of a specific transaction is paid in accordance with the energy multiplier of each transaction and the difference in LMPs between the sender and receiver. It can offer the proper correlation signal to set up a new TL and install the generator. However, it also entails people engaging in strategic competition with one another in an effort to maximise their profits [8].

#### 2.2 Uplift Cost

In addition to the uplift cost, the former British pool value has a standard congestion cost. It is speaking of the security cost, which is the price difference between supply constraints and unrestricted supply. Cost increases due to improved transmission services, rising energy prices, an increase in reactive power, and compensation for unplanned availability. The explanation is given in [4] in detail.

 $PPP = SMP + CP \tag{1}$ 

$$PSP = PPP + Uplift$$
 (2)

#### Where,

SMP	it is a marginal unit (highest Reach the
	expensive generators needed for
	prediction) market demand
PPP	this is the previously calculated price of
	trading day, stand for pool purchase price
PSP	this is the payment made by the buyer
	and pay to generator, stand for pool sales
	price
СР	available capacity payment, whether the
	power production by generator is taking
	place or not
TT 11C	

- Uplift additional fees paid for transmission (including the loss of the transmission system), and unlimited timetable with transaction cost
- Bid variable cost which is already

Price predetermined

Make adjustment computations to compensate generators if private generators are chosen in an environment with no restrictions on scheduling but are unable to generate power due to system limitations.

It must now be postponed if the original timetable violates security restrictions. The PPP fee, which is less than the bid price, is typically assessed to the generator during the rescheduling process. This also necessitates correction computation.

The cost of adjustment is then included in the revenue of generator.

However, the generator doesn't specifically charge for congestion charges.

#### 2.3 Price Area Congestion Management (PACM)

India and the Nordic countries are where this practise is most popular. It is supported by a decentralised, two-sided market that moves with the day. Each zone offers several bids with various loads and generators [9]. The system

price (P) is initially determined by taking into account all bids and offers. When there are substantial flows between auctioning locations, the area price (P) is computed. The capacity cost, or the difference between P and P, provides insight into the installation of additional units. The price is controlled in the areas of power surplus and deficit in such a way that the capacity of the line is maintained for the flow of power between these areas.

#### 2.4 Congestion Management Based on ATC

ATC stand for "available transfer capability." This refers to additional amount of power that can be delivered through TL.

$$ATC = TTC - TRM - (ETC + CBM)$$
(6)

Where,

TTC	maximum power that can be transmit
	through network meeting all the safety
	constraint.
TRM	margin required for system uncertainty condition
ETC	existing transfer commitment
CBM	the reserved margin by load serving units for reliability of generation
	requirements

The ATC data for a line is recorded and stored by ISO before being sent to the OASIS website, which is managed by ISO. Active Congestion Transmission Power Factor (PTCDF), Optimum Power Flow, Line Outage Distribution Factor (LODF), and Continuation technique are the four ways that can be used to calculate ATC. One of the fundamental strategies for clearing congestion in TL is ATC. In many places, it is currently the tactic that is used the most. ATC is a crucial element in the determination of TL. A technique to use the OPF to compute ATC with constant power and then simulate the FACTS device has been proposed by the author of [10]. then consider how FACTS devices have an effect on TL's ATC. The findings indicate that the use of UPFC and Sen Transformers increases ATC. The next sections provide a detailed description of the FACTS equipment that was discussed.

#### 2.5 FACTS Devices

For CM, there are two approaches. 1) a free way, and 2) an expensive method. Methods that are free have additional advantages because there is no economic inequality involved. It also includes the TCSC and UPFC devices from FACTS.

FACTS devices come in three different flavours: series controllers, shunt controllers, and combination series/shunt controllers. By regulating the flow of line power, series controllers like TCSC, SSSC, and TCPAR can reduce overloading and increase gearbox capacity. Shunt controllers, like SVC, can correct voltage on the low voltage bus by injecting reactive power directly or indirectly. To alleviate power flow congestion in TL and enhance the voltage profile, combination series-shunt controllers, such as UPFC, are employed. The position of numerous FACTS devices has been optimised by Song using optimisation technology that takes safety indicators into account in [11]. Performance of the proposed technique was observed on the IEEE-57 bus system with FACTS devices functioning both normally and unexpectedly. Yu and Lushan established a welfare programme in [12] that was in place for a while. maximised model that takes into account losses when installing FACTS devices in a deregulated electricity system. The findings indicate that the FACTS devices cannot be added on an hourly basis; instead, a sufficient number of hours must pass before the best device location has been found.

The most advanced technology in the present electricity system, FACTS and optimisation approaches together, efficiently alleviate congestion. Transmission capacity, voltage stability, and safety restrictions can all be easily increased with the use of FACTS devices. Using FACTS devices, Reddy et al. tried to identify the CM techniques. For the best placement of FACTS devices, the authors employed GA [13].

The most recent FACTS device that is frequently used nowadays for power flow regulation is the IPFC. The author of [14] proposes a novel approach that combines IPFC with the best possible power flow. Power flow can be managed by IPFC in a multiplex line.

Karami et al. created a plan to simultaneously calculate the IPFC's appropriate capacity and the STATCOM's optimal solution location for managing congestion. The optimisation strategy used in the suggested method is based on artificial intelligence [15].

To optimise the placement of TCSCs, Besharat and Taher presented active power indicators and a strategy focused on reducing system reactive power losses [16]. In this paper, two methods for determining device position sensitivity are used. They have five buses and two power systems integrated. The outcome of this method implies that the ideal location can be determined using the sensitivity factors and Gitizadeh and Kalantar conduct-TCSC costs. ed a thorough analysis of the TL application of FACTS devices. The sequential quadratic programming (SQP) problem is used by the author to evaluate static security margin and congestion reduction requirements. Additionally, the simulated annealing method is used to solve the optimisation problem [17].

Rajalakshmi discussed the effectiveness of FACTS devices in [18] and how using these devices can increase a line's capacity for transfer. According to performance indicators and overall VAR losses, the author has suggested a technique for correctly finding FACTS devices. Masoud E. et al.'s [19] suggestion for CM was a multi-objective

(MO) structure in which the three goals are being fulfilled simultaneously. Voltage, overall operating costs, and transient stability margin are all included in the objective. Using location marginal price (LMP), the suggested method efficiently locates and establishes the size of the sequence FACTS equipment on the highest priority line list.

FACTS technology reduces the expense of congestion brought on by the best position. Numerous optimisation technologies have been applied where they belong on the TL. The following sections generally classify the information, some of which is illustrated.

# 3. Expert system and techniques of optimization

In essence, CM is a non-linear programme with a large number of variables. The optimisation algorithm can be used to solve this program's problem [20]. In the sections that follow, expert system methodologies, several alternative evolutionary strategies, and the most effective and widely used optimisation techniques are also covered.

#### 3.1 Genetic Algorithm

One of the effective optimisation methods used to address a variety of non-linear programming issues, more specifically in the trading of commodities, is GA. Chromosome theory is used to show the GA technique with CM.

A method for assisting system operators in a power transmission system to find its ideal design is suggested by Granelli G. et al. [21]. This tool is appropriate for CM problems. The author validates the work of the 33 bus CIGRE example system using the Italian 432 bus EHV network. They start by modelling the reconfigurations problem as a linear programme with variables, using deterministic approaches. Second, GA can be used to preserve M and M-1 security constraints in MO optimisation issues.

S. Reddy et al. explain the single and MO optimisation strategies in [22] for the ideal location and size of FACT devices in the TL. GA were initially used for single-objective optimisation. For MO optimisation, SPEA-which takes into account several objective functions at once-was subsequently introduced. In GA, a random population must first be created for the sample size, and from there, selection, crossover, and mutation are used to improve the population. For the configuration of FACTS devices, three criteria are used: location, kind, and rating. Everybody has numerous demands for a compromise. Location, kind, and ratings are each represented by three values. SPEA is utilised for MO optimisation, but it is not the sole method of congestion management.

#### 3.2 Particle Swarm Optimization (PSO)

PSO is an evolution algorithm for FACTS device location optimisation. Saravanan described how the PSO algorithm was used to locate FACTS devices such the TCSC, SVC, and UPFC in the best possible place [23]. It increases system load capacity and is less expensive. As a test system for simulation, Tamil Nadu Electricity Board utility systems and IEEE multiple bus systems such 6, 30, and 118 are used. The author discovered that TCSC requires less installation cost and provides superior load ability than UPFC, which can deliver the greatest system load capacity in IEEE tests. For improved positioning of FACTS devices, in [24] NSPSO, which stands for NonDominated Sorting Practical Swarm Optimisation, is an improvement on the conventional PSO made by Benabid R. et al. for MO optimisation issues. The entire population is stored using this technique in many non-dominant fronts. The first front in the population's running condition is entirely a non-dominant set, whereas individuals rule the second front in the first front, and so on.

The outcome is validated using the Algerian 114-bus system and the IEEE 30-bus system. It is possible to produce low power loss, little voltage deviation, and increased static voltage margin.

Panida et al. propose a time-varying acceleration coefficient, also known as PSOTVAC in conventional PSO, to obtain the best CM. The algorithm was evaluated on IEEE-118 and IEEE-30 bus systems, and the outcomes were compared to those of traditional PSO and PSO-TVIW. With the exception of the shrinking coefficient velocity equation and the linear drop in weight of inertia with each iteration, the concept of PSO-TVIW is the same as the original PSO. The prior extension, PSO-TVAC, alters its coefficients with each repetition.

This is a powerful optimisation technique based on biological behaviour. "Swarm" is a particle representation of a group. Here, each particle has two vectors: a position vector and a velocity vector. PSO was used to address congestion management difficulties by Joshi and Pandya [25]. The Newton-Raphson method (NRM) was utilised by the author to check for overload lines and then determine the sensitivity factor. Using the sensitivity factor, identify the generators connected to the busiest lines before applying PSO. The value of the vector would indicate how much voltage and real power were to be rescheduled. The load stream for the NR Method is active. Voltage amplitude, line flow, line flow value, and active and reactive power rescheduling are all obtained.

#### 3.3 Bacterial Foraging Algorithm

R. Pandi and Panigrahi put forth a novel concept. The fittest will survive in every circumstance, according to the evolution idea. This algorithm is called 'bacterial foraging approach'. It uses a random optimisation approach. The behaviour of E. coli bacteria can be used to describe strategy and this algorithm. The four stages of survival for these bacteria in the human intestine are crowding, chemical taxis, reproduction, and elimination-dispersal. The Nelder-Mead approach was intended to be used in conjunction with the aforementioned strategies to address the CM problem. The author concludes that this approach is superior to GA and swarm optimisation [26].

Using the fuzzy adaptive bacterial foraging (FABF) approach, optimal active power rescheduling helps to alleviate the congestion issue [27]. The generator is chosen based on its sensitivity to clogged lines, and the outcome is contrasted with PSO and traditional bacterial foraging. IEEE-30 bus and Indian 75-bus systems are used to verify the results.

#### 3.4 Approach of Expert System and Evolutionary Strategies

Every possible configuration of TLs must be examined in order to prevent various congestion problems. This could assist ISO in locating the most stable condition. A CM system executes every scenario. a linear programming issue with mixed integers. It makes use of the corrective generator switching principle. Numerous serious size issues can result from topological alterations. These kinds of issues can be resolved via evolutionary techniques.

For the problem of congestion, the author of [28] N. P. Padhy offers a hybrid model. In the first stage, reduction strategies are found for a given set of active and reactive powers using the traditional best algorithm. In the second stage, the best transaction fuzzy logic matrix selection approach is applied. The efficiency of the model has been confirmed on the IEEE 30 bus system.

Yeuranatam and D. Thukaram suggested an expert system method to a secure and cost-effective electricity system in [29]. By lowering the cost of rescheduling, the proposed approach is used in the process. This ideal cost is based on the relative electrical distance (RED) of the generator and the incremental fuel cost notion.

In [30], to estimate ATC the author proposed hybrid mutation PSO (HMPSO) Technology. First, the author used GA, PSO to achieve the same purpose. Secondly, in this paper use of the following two FACTS devices SVC and TCSC to optimize the installation as well as allocation of capacity of FACTS equipment by the MO optimization technique. IEEE-30 and IEEE-57 bus systems are used for the verification of result.

S. Abbas and Karim devised the hybrid immune algorithm (HIA) in [31] to place the UPFC properly for efficient power flow. When the outcome is compared to GA, PSO, and IA, IPSO algorithms are found to produce superior outcomes. It provides entire active and reactive power produced at the lowest cost. For result verification, bus systems based on IEEE-30 and IEEE-14 are employed.

By utilising fuzzy logic ideas, Bhattacharyya and Gupta [32] have decreased congestion. The authors identify the FACTS devices, including TCSC and SVC, that are best located. The author comes to the conclusion that fuzzy logic is the best methodology after contrasting this approach with others.

In order to calculate the effects of these FACTS devices on the electricity system, Tarafdar Hagh develops STATCOM and SSSC. The author utilises an index to quantify predictability, emphasises its significance in optimisation, and cautions power system operators not to neglect this issue. Results are verified using the IEEE 14-bus and IEEE 57-bus systems [33].

#### 4. Demand response management

Demand response management permits customer interference in the electricity market. It has two main policies: Generation re-dispatch and Emergency Demand Response Management (EDRP).

According to the following two criteria, demand response is classified: Time and rewards, respectively. The EDRP programme is incentivebased. Typically, consumers who want to save electricity are involved. The incentive for the consumer will be covered by the consumer.

Yousefi A. et al. proposed a congestion approach in [34] by combining two methods: (i) FACTS device optimal positioning methods and (ii) demand response. It can be done as shown below. First, using the ISO's social welfare function, determine the market price. Step 2: Network restrictions are taken into account for managing congestion. This paper's primary area of attention is on the ()  $()()^{()}$  (7)

CM discussed by Kumar and Sekhar in their paper [35] is by the same method as [34]. The keys differences of these papers are (i) used test system (ii) the of congestion cost (iii) the consideration of congestion.

# 5. Congestion management adapted in various countries

Here in this paper the main focused on USA and European countries. The scenario of congestion and its management in these countries are explored below with detail in the following section

#### 5.1 Congestion Management in USA

There are two different types of congestion in the US power market, according to [36]. Centralise first, then decentralise later. LMP is the foundation of the centralised CM approach. This is an illustration of PJM interconnection. In PJM, participants pool resources and coordinate dispatch. It thus becomes the biggest dispatch centre in North America. For the purpose of minimising congestion, the PJM Network's 1750 buses' calculated LMP is posted on the OASIS website every five minutes. Because of this, PJM permits participants to hedge by monitoring shadow prices that are published on OASIS via FTR. While flow and area control are included in the decentralised approach in TL; DR: It is assumed that there is relatively little congestion in the area. As a result, monitoring congestion solely between regions is required. Such complaints of CM technology are common. Congestion management is a key component of CM and is handled by NERC, FERC, and regional commissions. System-related organisations operate as a single entity, yet there are certain functional distinctions between them. FERC is devoted to promoting free and open markets. NERC draws attention to the technical reliability issues. Additionally, ISO is in charge of the CM in the transmission network.

#### 5.2 Congestion Management in Europe

By 2020, member countries of the European Commission intend to integrate renewable energy sources into their electrical systems [37,

38]. Congestion is brought on by an increase in these sources since it results in new currents and power transfer. implemented pricing strategies in the United States, gaining experience in congestion control. Europe too has a propensity to veer off course. The application of locational marginal pricing is emphasised throughout Europe. Even though regional pricing has been implemented in the Nordic nations and multiple zones have been created within their power transmission networks in nations like the Netherlands, Belgium, Germany, France, and Luxembourg, this CM technique has not yet gained widespread acceptance in the European electricity markets. It can also be seen as a drawback of the electrical market in the United States. It is challenging has seen bilateral dealings in Europe. LMP appears to be the CM approach most appropriate for bilateral trade in the electricity market of the European Union. Additionally, by switching bus nodes, smoother bilateral trade transactions are made possible by the availability of financial transmission rights. LMP therefore supports the principle of bilateral transactions.

The German electricity power market has restructured because of problems faced by the interconnection of renewable energy with grid. Germany's four TSOs are in charge of handling the congestion issue. TSOs used Nash equilibrium to coordinate developing processes. Consequently, effective coordination will reduce the overall cost of congestion.

## 6. Conclusions

This essay covers a thorough and critical assessment of opinions on congestion management. The initial analysis emphasised conventional CM techniques. discussions that were necessary and significant for each segment. The effectiveness of optimisation techniques in reducing congestion has also been demonstrated. The author makes an effort to incorporate nearly practical optimisation methods in the CM that has been researched. Many scholars are looking into novel processes to make things easier, like pool dispatch schemes and evolution strategies. The majority of the most recent advancements in this field are covered. The technology used in Germany, other European nations, the United States, etc. is also discussed in this
review. Anyone involved in the electricity industry needs to do their homework, be knowledgeable, and be aware of the system's issues. It is anticipated that anyone involved in this field will find it valuable. With the help of this document, research scholars can broaden the area of their study and develop more effective, timely answers. Additionally, the author offers remedies for CM. Problems can also be solved by taking factors like water intake load and random variables into consideration.

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### 55. Analysis of MRR and surface roughness modeling in stainless steel using response surface methodology

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#### Abstract

The objective of this research is to study the effect of cutting speed, feed, depth of cut, machining time on metal removal rate, specific energy, surface roughness, volume Fraction and flank wear. The present work is focused to study the effect of process parameters such as spindle speed, feed rate and depth of cut on surface roughness and MRR using DoE, Response Surface Methodology (RSM), ANOVA and Grey relational analysis. The experimental analysis highlights that the turning operation characteristics like MRR and SR on SS 304 are influenced by the various major machining parameters.

Keywords: ANOVA, MRR, SS304, RSM

#### 1. Introduction

Turning involves the elimination of material from the outer surface of a cylindrical workpiece in motion. This process aims to decrease the workpiece's diameter, typically to a predetermined size, while also achieving a polished texture on the metal. Frequently, the workpiece is rotated to create varying diameters in adjacent segments. Essentially, turning is the manufacturing technique responsible for creating cylindrical components. In its fundamental manifestation, it can be characterized as the procedure of shaping an external surface:

- With the work piece rotating,
- With a single-point cutting tool, and
- With the cutting tool feeding parallel to the axis of the work piece and at a distance that will remove the outer surface of the work.

In a study conducted by Feng and Wang (2002), an exploration was undertaken to forecast surface roughness in finish turning processes. This was achieved by formulating an experiential model that took into account several operational factors, including workpiece hardness (material), feed rate, cutting tool point angle, depth of cut, spindle speed, and cutting duration. Data mining techniques, nonlinear regression analysis with logarithmic data transformation were employed for developing the empirical model to predict the surface roughness.

Suresh et al. (2002) focused on machining mild steel by TiN-coated tungsten carbide (CNMG) cutting tools for developing a surface roughness prediction model by using Response Surface Methodology (RSM). Genetic Algorithms (GA) used to optimize the objective function and compared with RSM results. The observation revealed that the genetic algorithm program furnished both the lowest and highest extents of surface roughness, along with the corresponding optimal machining parameters.

Lee and Chen (2003) highlighted on artificial neural networks (OSRR-ANN) using a sensing technique to monitor the effect of vibration produced by the motions of the cutting tool and work piece during the cutting process developed an on-line surface recognition system. The researchers utilized a tri-axial accelerometer to ascertain the vibration direction's notable impact on surface roughness. Subsequently, they analyzed this data employing a statistical approach and proceeded to compare the predictive precision of both artificial neural networks (ANN) and stochastic modeling regression (SMR).

Choudhury and Bartarya (2003) concentrated on employing experimental design and neural networks to forecast tool wear. They considered cutting speed, feed rate, and depth of cut as input parameters, while flank wear, surface finish, and cutting zone temperature were chosen as output variables. They established empirical connections linking various responses to input factors and employed a neural network (NN) program to aid in predicting all three response variables. They then compared the effectiveness of both methods in prediction.

In a similar vein, Chien and Tsai (2003) devised a model for anticipating tool flank wear, followed by an optimization model to identify the best cutting conditions for machining 17-4PH stainless steel. To build the predictive model, they employed a back-propagation neural network (BPN). Furthermore, they harnessed the power of genetic algorithms (GA) to optimize the model and determine the optimal conditions.

Kirby et al. (2004) formulated a predictive model for surface roughness in turning operations. They constructed a regression model based on a single cutting parameter and selected vibrations along three axes to establish an in-process surface roughness prediction system. Through the utilization of multiple regression and Analysis of Variance (ANOVA), a robust linear correlation was identified between the parameters (feed rate and vibrations measured along three axes) and the outcome (surface roughness). The authors illustrated that spindle speed and depth of cut might not necessarily need to be held constant for an effective surface roughness prediction model.

Özel and Karpat (2005) conducted a comparative study utilizing neural network and regression models to predict surface roughness and tool flank wear. They employed a dataset comprising measured surface roughness and tool flank wear to train the neural network models. These predictive neural network models exhibited enhanced forecasting capabilities for surface roughness and tool flank wear within the range where they were trained.

Luo et al. (2005) performed both theoretical and experimental investigations to explore the inherent connection between tool flank wear and operational conditions in metal cutting processes using carbide cutting inserts. The authors devised a model to anticipate the width of the tool flank wear land, amalgamating cutting mechanics simulation with an empirical model. The research unveiled that cutting speed wielded a more pronounced impact on tool lifespan than feed rate.

Kohli and Dixit (2005) proposed a neural-network-based methodology with the acceleration of the radial vibration of the tool holder as feedback. For the surface roughness prediction in turning process the back-propagation algorithm was used for training the network model. The methodology was validated for dry and wet turning of steel using high speed steel and carbide tool and observed that the proposed methodology was able to make accurate prediction of surface roughness by utilizing small sized training and testing datasets.

Pal and Chakraborty (2005) conducted research focused on creating a back propagation neural network model to forecast surface roughness in turning operations. They employed mild steel workpieces and high-speed steel cutting tools to conduct an extensive array of experiments. The authors used speed, feed, depth of cut and the cutting forces as inputs to the neural network model for prediction of the surface roughness. The work resulted that predicted surface roughness was very close to the experimental value.

Őzel and Karpat(2005) developed models based on feed forward neural networks in predicting accurately both surface roughness and tool flank wear in finish dry hard turning.

Singh and Kumar (2006) conducted research centered around the optimization of feed force by determining the ideal values for process parameters, including speed, feed rate, and depth of cut. This optimization was carried out during the turning of EN24 steel using TiCcoated tungsten carbide inserts. The authors used Taguchi's parameter design approach and concluded that the effect of depth of cut and feed in variation of feed force were affected more as compare to speed. Ahmed (2006) established the necessary approach to determine optimal process parameters for forecasting surface roughness in aluminum turning. To create an empirical model, nonlinear regression analysis was employed, involving the transformation of data using logarithmic methods. The resulting model displayed minor errors and yielded satisfactory outcomes. The study's findings indicated that employing a low feed rate was advantageous in achieving reduced surface roughness, while higher speeds could yield enhanced surface quality within the tested range of conditions.

Abburi and Dixit (2006) designed a knowledge-based system to anticipate surface roughness in turning processes. They harnessed fuzzy set theory and neural networks for this purpose. The authors formulated rules to predict surface roughness based on given process variables, as well as to forecast process variables corresponding to a specified surface roughness value.

Zhong et al. (2006) conducted a study to forecast surface roughness on turned surfaces utilizing networks with seven inputs, namely tool insert grade, workpiece material, tool nose radius, rake angle, depth of cut, spindle rate, and feed rate.

Kumanan et al. (2006) proposed a method for predicting machining forces using a multi-layered perceptron trained with a genetic algorithm (GA). Experimental results from a turning process were utilized to train the artificial neural networks (ANNs) with three inputs, producing machining forces as the output. Optimal ANN weights were determined through a GA search. This hybrid approach, combining GA and ANN, proved both computationally efficient and accurate in predicting machining forces based on input conditions.

Mahmoud and Abdelkarim (2006) examined turning operations using a High-Speed Steel (HSS) cutting tool with a 450 approach angle. This tool demonstrated the ability to conduct cutting operations at higher speeds and with a longer tool life compared to traditional tools with a 900 approach angle. The study ultimately identified an optimal cutting speed to achieve high production rates while minimizing costs, including tool life, production time, and operation expenses.

Doniavi et al. (2007) employed response surface methodology (RSM) to develop an empirical model for predicting surface roughness by determining the optimal cutting conditions in turning. The authors highlighted the significant influence of feed rate on surface roughness; higher feed rates correlated with increased roughness. Conversely, increased cutting speed led to decreased surface roughness. Analysis of variance indicated that feed rate and speed had a more pronounced impact on surface roughness compared to depth of cut.

Kassab and Khoshnaw (2007) investigated the connection between surface roughness and cutting tool vibration during turning operations. Process parameters such as cutting speed, depth of cut, feed rate, and tool overhang were explored through dry turning (without cutting fluid) of medium carbon steel at varying parameter levels. Dry turning facilitated a strong correlation between surface roughness and cutting tool vibration due to a clean working environment. The authors established a robust correlation between cutting tool vibration and surface roughness, enabling control over workpiece surface finish during mass production.

Al-Ahmari (2007) developed empirical models for tool life, surface roughness, and cutting force in turning operations. Process parameters including speed, feed, depth of cut, and nose radius were employed to establish a machinability model.

The objective of this research is to investigate the impact of cutting speed, feed rate, depth of cut, and machining time on metal removal rate and surface roughness. Using the RSM method, the aim is to determine the optimal parameter combination that maximizes metal removal rate while minimizing surface roughness. Taylor's work demonstrated the existence of an optimum or economic cutting speed that can maximize material removal rate. However, challenges persist in establishing optimal machining conditions and selecting appropriate cutting tools due to various practical constraints such as machine tool power, torque, force limits, and component surface roughness.

Surface quality between machined surfaces significantly affects the performance and wear of mating parts. The characteristics of surface irregularities on the workpiece depend on factors such as machining variables (cutting speed, feed, and depth of cut), tool geometry (nose radius, rake angle, side cutting edge angle, and cutting edge), workpiece and tool material properties, machine tool quality, auxiliary tooling, lubrication, and vibrations between the workpiece, machine tool, and cutting tool.

### 2. Experimental Setup and Methodology

Experiments were designed for turning operation on Stainless steel (SS304) material using single point cutting tool having carbide tip. Turning operations were performed on 30 mm diameter shaft of SS 304. A total of 20 nos. of Experiments obtained from RSM rotatable central composite design having 3 input factors (spindle speed, feed, depth of cut) has been selected for surface roughness and MRR measurement. MRR is calculated online during machining using the Weight Machine & stopwatch. Surface roughness for each combination of experiment is measured after completion of machining using MITUTOYO Surface roughness tester SJ-301. SS304 cylindrical Shaft is precisely placed Universal 3 jaw chuck.

The machining was carried out in conventional Lathe Manufactured by Dhillon Machinery Corporation, The lathe has speed ranging from 225 to 820 rpm and it has feed rates ranging from 0.065 to 0.99 mm/rev. RPM was measured using tachometer.

#### 3. Methodology

Experiments have been carried out in dry conditions on the conventional lathe machine. The work material used was Stainless Steel (SS-304). The tool material used in the experimental work is coated carbide grade of specification.

In the present study, three levels of process parameters i.e. spindle speed, feed rate and depth of cut were selected. The levels of process parameters and their values are shown in Table 1.

Table	1:	Process	parameters
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Process parameters	Unit		Levels	
		-1	0	1
Speed	(rpm)	350	585	820
Feed	(m/min)	0.12	0.26	0.4
Depth of Cut	(mm)	0.1	0.2	0.3

#### 4. Results and Discussion

#### 4.1 Experiments based on RSM

Table 2 shows the experimental data of responses surface roughness (Ra) and Material removal rate (MRR). The surface roughness was obtained in the range of (1.65-6.5) and MRR in the range of (0.08-0.96) respectively. The results are put in MINITAB 17.1 statistical software for further analysis.

Table 2:	Experimental design-CCD matrix and	d
measured	value of responses	

S. No.	Speed (rpm)	Feed ((m/ min)	Depth of Cut (mm)	Ra (Mi- crons)	MRR (Gm/ Min)
1	350	0.4	0.1	6.5	0.103
2	585	0.26	0.1	2.33	0.433
3	350	0.12	0.1	3.271	0.012
4	350	0.26	0.2	4.65	0.033
5	585	0.12	0.2	3.38	0.047
6	820	0.4	0.3	3.15	2.65
7	820	0.12	0.3	3.32	0.075
8	820	0.4	0.1	2.48	0.412
9	585	0.26	0.3	2.19	0.691
10	585	0.26	0.2	2.37	0.08
11	350	0.4	0.3	8.76	0.125
12	585	0.26	0.2	2.54	0.08
13	350	0.12	0.3	3.46	0.125
14	585	0.4	0.2	5.87	0.123
15	585	0.26	0.2	2.54	0.08
16	820	0.12	0.1	1.65	0.96
17	820	0.26	0.2	2.37	1.05
18	585	0.26	0.2	2.54	0.08
19	585	0.26	0.2	2.54	0.08
20	585	0.26	0.2	2.54	0.08

The second-order model was postulated in obtaining the relationship between the surface roughness parameters and the machining variables. The analysis of variance (ANOVA) was used to check the adequacy of the second-order. In order to judge the ability and efficiency of the model to predict the surface finish values percentage deviation ( $\phi$ ) was calculated using Eq. 1.

$$\varphi = \frac{Experimental - \Pr{edicted}}{Experiental} x100 \tag{1}$$

where,  $\Phi$  is the percentage of deviation of single sample data.

#### 4.2 Development of Empirical Model Based on Response Surface Methodology

Ra (microns) = 2.700 - 1.367 n(rpm) + 1.168feed (m/min)+ 0.465 depth of cut (mm) + 0.526 N(rpm)\*N(rpm) +1.641 feed (m/min)\* feed (m/ min) - 0.724 depth of cut(mm)\*depth of cut (mm) - 0.984 N(rpm) \*feed(m/min) - 0.014 N(rpm)\*depth of cut (mm)+ 0.134 feed (m/ min)\* depth of cut (mm)......(2)

#### 4.3 Development of Empirical Model Based on Response Surface Methodology for MRR

MRR= 0.148+ 0.475 N (rpm)+ 0.219 feed (m/ min) + 0.175 depth of cut (mm) + 0.290 N (rpm)\*N (rpm) - 0.166 feed(m/min)\*feed(m/ min) + 0.311 depth of cut (mm)\* depth of cut (mm) + 0.242n (rpm)\*feed (m/min) + 0.152 n(rpm)\*depth of cut (mm) + 0.379 feed (m/ min)\*depth of cut (mm)......(3)

#### 4.4 Influence of Process Parameters on Surface Roughness and MRR

The parametric analysis has been carried out to study the influences of the process parameters such as N (RPM), Feed (mm/rev) and Depth of cut (mm) on the machining responses i.e. Material Removal Rate (MRR) and Surface Roughness (Ra) during Turning operation based on the developed empirical models as established through RSM and response surface plot and contour plot using MINITAB software.

#### 4.5 Influence of Process Parameters on Surface Roughness (R<sub>a</sub>)

4.5.1 Influence of Spindle Speed (N rpm) and Feed Rate (mm/rev) on Surface Roughness (R)

From Figure 1, with increase in spindle speed, it is observed that surface roughness decreases. The reason being that when the spindle speed is increased, the frictional force between the cutting tool and the work piece decreases, and provides a smooth surface. With increase in feed, the surface roughness also increases. As the feed is increased, the time of contact between the tool and the work piece decreases, thereby increasing roughness.



Figure 1 Surface Plots for Surface Roughness vs. Speed (N) (rpm)

### 4.5.2 Influence of Feed (mm/rev) and Depth of Cut on Surface Roughness $(R_a)$

From the Figure 2, with increase in feed, the surface roughness value generally increases or it follows an increasing trend. With increase in feed, the contact time between the tool & the work piece increases & hence the surface roughness increases. It is seen that with an increase in the depth of cut, the surface roughness increases. As depth of cut is increased, the MRR increases, thereby removing large amount of material & henceforth increasing the surface roughness.



Figure 2 Surface plot for surface roughness vs. feed (m/min) and depth of cut (mm)

#### 4.5.3 Influence of Spindle Speed (N) and Depth of Cut (mm) on Surface Roughness (R<sub>2</sub>)

From the Figure 3, it is observed that with increase in spindle speed the surface roughness decreases. As the speed increases, the frictional force between the tool & the work piece decreases, hence providing a smooth surface. With increase in depth of cut, it is seen that the value of surface roughness increases because the MRR increases & thereby providing a rough surface.



Figure 3 Surface plots for surface roughness vs. speed (N rpm) and depth of cut (mm)

#### 4.6 Influence of Process Parameters on Material Removal Rate (MRR)

#### 4.6.1 Influence of Spindle Speed (N rpm) and Feed Rate (mm/rev) on MRR

From the graph on the Figure 4, it is observed that with an increase in spindle speed, the MRR increases linearly. The reason being that the cutting force increases with the increase in spindle speed, thereby removing larger amount of material. With increase in feed, it is observed that the MRR increases; the contact time between the tool & the work piece increases when feed increases, thereby removing large amount of material.



Figure 4 Surface plot for MRR vs. speed (N rpm) and feed rate (m/min)

#### 4.6.2 Influence of Spindle Speed (N rpm) and Feed Rate (mm/rev) on MRR

From the graph on the Figure 5, it is observed that with increase in spindle speed, the MRR increases due to increase in cutting force. The MRR increases with increase in depth of cut. The reason being that with increase in depth of cut, more cutting force is exerted & hence more material is removed.



Figure 5 Surface plot for MRR vs. speed (N rpm) and depth of cut (mm)

#### 4.6.3 Influence of Spindle Speed (n) and Depth of Cut (mm) on MRR

From the graph on the Figure 6 with increase in feed, the MRR increases. It is because the contact time between the tool & the work piece increases & thus removing greater amount of material. With increase in depth of cut, the cutting force increases and thus increasing the MRR.



Figure 6 Surface plots of MRR vs. feed (m/min) and depth of cut

#### 5. Multi-objective Optimization of Turning Operation

For achieving optimal parametric combination during turning operation of SS-304, multi-objective optimization has been performed using MINITAB software. The multi-objective optimization result during turning operation of SS-304 is shown in Figure 7. In the mentioned Figure, columns of the plot signifies each parameter with their ranges considered and each row of the plot represents the performance criteria measured in this experimentation. Moreover, each cell shows how the process criteria changes as function of one of the process parameters while keeping the other parameters fixed. From this Figure, the optimal parametric combination for multi-objective optimization was obtained: speed = 820 rpm, feed = 0.31 mm/rev, depth of cut = 0.3 mm. The maximum MRR of 1.856 g/min and minimum SR (Ra) value of 1.96 µm are obtained at the optimal parametric combination based on RSM. During multi-objective optimization, all the responses were optimized with composite desirability (D) value of 1.



Figure 7 Multi objective optimization of turning operation

#### 6. Conclusion

The experimental analysis highlights that the turning operation characteristics like MRR and SR on SS 304 are influenced by the various major machining parameters. The optimal parametric condition for achieving maximum MRR and minimum surface finish analysis has been done by RSM. Based on RSM models the multi-objective optimization is done to find the optimal values of the turning operation process parameters for maximum MRR and minimum SR. The optimal parametric setting are obtained is: speed= 820 rpm, feed = 0.31 mm/rev, depth of cut =0.3mm. The maximum MRR of 1.856 g/min and minimum SR (Ra) value of 1.96 µm are obtained at the optimal parametric combination based on RSM.

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## 56. An investigation into the performance characteristics of a rear-supported V-cone flowmeter

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#### Abstract

Flow measurement is a vital parameter across diverse industries, encompassing oil and gas, chemical processing, and water management, where precise quantification holds utmost importance. The V-Cone flowmeter, a distinctive differential pressure-based apparatus, has garnered recognition for its unparalleled accuracy, unwavering reliability, and remarkable low-pressure drop attributes. This comprehensive research endeavour is singularly focused on an exhaustive exploration of the operational efficacy of a rear-supported V-Cone flowmeter. The investigation employs a meticulously crafted synergy between empirical investigations and sophisticated numerical simulations to delve into the performance intricacies of the rear-supported V-Cone flowmeter. The far-reaching implications of this pursuit encompass not only a scientific elucidation of the rear-supported V-Cone flowmeter's capabilities but, more significantly, its practical viability. The eventual amalgamation of empirical evidence and computational insights crystallizes into a panoramic understanding of the flowmeter's performance nuances. This, in turn, catapults our comprehension of its potential within real-world applications, offering invaluable insights for industries where accurate flow measurement is not just a technicality but a prerequisite for operational efficiency, reliability, and safety.

In summary, this research enterprise serves as a beacon, illuminating the multifaceted aspects of the rear-supported V-Cone flowmeter. Through a comprehensive evaluation encompassing accuracy, pressure recovery, and turndown ratio, facilitated by empirical investigation and numerical exploration, the study harmonizes theory and application. Ultimately, the findings serve as a cornerstone, fostering an enriched comprehension of the rear-supported V-Cone flowmeter's capabilities, charting its trajectory towards enhanced utility across industries that hinge on seamless and precise flow measurement.

Keywords: V-Cone flowmeter, differential pressure, rear-supported, flow measurement, accuracy, pressure recovery, turndown ratio.

#### 1. Introduction

Flow measurement is crucial in numerous industrial processes to optimize operations and ensure efficiency. The V-Cone flowmeter has gained popularity due to its unique design, which provides accurate and reliable flow measurements with minimal pressure loss. However, the performance of rear-supported V-Cone flowmeters needs further investigation to validate their capabilities and identify potential limitations. In certain industries, such as petroleum refining, accurate measurement of fluid flow is a challenge due to disturbances in the upstream flow. This is often caused by limited space, leading to the installation of flow meters in areas with disruptions like valves, elbows, pumps, bends, and other piping components. Traditional flow measurement devices like orifice meters, Rota meters, and flow nozzles have strict requirements for minimum upstream and downstream pipe lengths, making them unsuitable for these conditions. These

devices can exacerbate flow disturbances, contributing to measurement inaccuracies when the required pipe lengths aren't maintained. To address these challenges, V-cone flow meters are employed. These meters alleviate the need for extensive upstream and downstream pipe lengths, enhancing measurement accuracy while saving both space and costs. Liptak (2003) elucidates the rationale behind the necessity for shorter pipe lengths. He explains that the space between the pipe and the cone element adjusts the velocity profile, evening out the flow speed at the center while increasing it in the peripheral region. This adjustment results in a more consistent velocity distribution. V-cone flow meters offer several advantages. They boast a claimed repeatability of ±0.1%, outperforming other flow-measuring devices which typically have a repeatability of ±0.2% according to experiments (Singh et al. 2006). Moreover, V-cone meters can achieve flow measurement accuracy within ±0.05% over a turn-down ratio of 30:1. This is a substantial improvement compared to traditional flow measuring devices that offer an accuracy of  $\pm 0.1\%$  over a turn-down ratio of 5:1 (Singh et al. 2009). In scenarios involving multiphase flows, particularly in liquid-gas mixtures, the V-cone meter demonstrates equivalent accuracy to that achieved in pure liquid flow measurement (Singh et al. 2010).

An additional advantage of V-cone flow meters is their reduced maintenance requirements. The flow's trajectory directly avoids the cone edge, mitigating wear on the edge itself. As a result, maintenance needs are minimized. V-cone flow meters find widespread use across diverse industries such as petroleum, aerospace, food, pulp, and paper, as well as metal and mining.

#### 2. Methodology

#### 2.1 Working Principle of V-cone Flowmeter

The experimental setup for performance evaluation of the rear-supported V-Cone flowmeter is described in detail. The flow tests are conducted using a range of flow rates, covering both laminar and turbulent flow conditions. Simultaneously, computational fluid dynamics (CFD) simulations are performed to complement the experimental data and gain insights into the flow behaviour within the flowmeter in relation (1). Obstruction-type flow meters are given as:

$$\mathbf{Q} = \mathbf{C}\mathbf{d} \times \frac{1}{\sqrt{1} - \boldsymbol{\beta}^4} \times \frac{\boldsymbol{\pi}}{4} \times \left(\mathbf{D}^2 - \mathbf{d}^2\right) \times \sqrt{2\boldsymbol{\rho} \cdot \mathbf{P}} \quad (1)$$

Here,  $\beta = \sqrt{\frac{D^2 - d^2}{D^2}}$  is the constriction ratio/ cone equivalence ratio.

For the present study, the pipe used has a diameter of 52.10mm and the highest diameter of the cone is 40mm for  $\beta$ =0.64. The length of the cone is 56mm and it is supported by a radial strut provided on the extruded portion downstream of the cone in Figure 2.



Figure 1. D-model of Rear supported v-cone flow meter

Differential pressure  $\Delta p$  is the pressure difference between two pressure taps. In the present case, the pressure difference is measured between 1D upstream and at the base of the cone downstream as shown in Figure 1.

#### 2.2 Geometry for Validation

The v-cone flow meter used for validation is front supported v-cone flow meter having  $\beta = 0.64$  with a maximum cone diameter of 40mm. The diameter of the pipe is 52.10mm. At the front there are four strut three aero foil shape struts at an angle of 120 degrees which are used to support the cone and the fourth cylindrical strut is for the pressure tap which measures the pressure at the base of the cone (in the experimental setup). The length of the pipe is 60D upstream and 22D downstream of the cone. The dimensions of the v-cone is given in Table 1. The geometry of the v-cone flow meter is made in SOLIDWORKS and then imported to ANSYS and the geometry of the flow domain is modeled in the ANSYS design modeler shown in Figures 3 and 4 respectively.



Figure 2. D-model of rear supported v-cone flow meter



Figure 3. Flow domain in Ansys design modeler (z-flow direction)



Figure 4 Experimental setup

Table 1 Dimensions of the v-cone

<b><i>β</i></b> -ratio	А	В	С	D	D	Е
0.64	18	30	8	40	52.10	18

#### 3. Results and Discussions

The collected data from the experiments and numerical simulations are analysed to assess the performance of the rear-supported V-Cone flowmeter. Parameters such as differential pressure, accuracy, pressure recovery, and turndown ratio are evaluated and compared under various flow conditions (Jazirian et al. 2023). The influence of Reynolds number, fluid properties, and geometric factors on the flowmeter's performance is also investigated. Here the simulations are done for different fillet radii at a constant Reynolds number of 30000. The results for rear support in case of different fillet radius is tabulated in Table 2.

Table 2 Results for rear support for different filletradius

Fillet radius	C <sub>d</sub>	% Deviation
		from mean
0.1 mm	0.8566	0.53
0.2 mm	0.8560	0.46
0.3 mm	0.8549	0.33
0.4 mm	0.8432	1.03
0.5 mm	0.8524	.29
0.6 mm	0.8545	.29
0.7 mm	0.8565	.52
0.8 mm	0.8514	.07
0.9 mm	0.8522	.02
1.0 mm	0.8401	1.39
1.1 mm	0.8435	1
1.2 mm	0.8573	0.61
1.3 mm	0.8542	0.25
1.4 mm	0.8526	.06
1.5 mm	0.8553	0.38

It can be seen from the table that the coefficient of discharge has a weak dependence on the fillet radius for the rear-supported v-cone flow meter. The maximum deviation of the Cd value from the mean value is 1%.



Figure 5 Graphical representation of results of v-cone flow meter with a fillet radius



Figure 6 Velocity contour for v-cone with fillet



Figure 7 Velocity streamlines

The findings of the study underscore the minimal impact of altering the fillet radius on the coefficient of discharge for a rear-supported V-cone flow meter in Figure 8. This observation could be attributed to the inherent design of the sharp-edged tapered cone, which adeptly guides the flow away from the cone's surface in a streamlined manner. This smooth

redirection of the flow plays a pivotal role in minimizing losses arising from the absence of vortices and eddies forming at the edge of the cone. The significance of the fillet radius lies in its potential to influence the flow behaviour near the edges of the cone. The presence of a fillet radius could potentially alter the flow patterns and induce disturbances in the boundary layer shown in Figure 5, leading to increased losses and variations in the coefficient of discharge. However, the study's outcomes suggest that the design of the V-cone, characterized by its sharp-edged and tapered nature, inherently manages the flow in such a way that the losses attributed to the absence of a fillet radius remain negligible. In essence, the streamlined flow directed away from the cone's surface helps to maintain a consistent and stable flow profile, mitigating the formation of disruptive vortices or eddies that might otherwise impact the coefficient of discharge. Consequently, even without the inclusion of a fillet radius, the losses associated with flow disruptions at the cone's edge appear to have a minimal effect on the coefficient of discharge value (Prabu et al. 1996).

Overall, the study's findings highlight the effectiveness of the V-cone's design in managing flow dynamics and minimizing losses, thereby contributing to the observed negligible impact of fillet radius variations on the coefficient of discharge for the rear-supported V-cone flow meter shown in Figures 6 and 7.

#### 3.1 Valve at 5d Upstream

The same boundary condition as used above is used here. The boundary condition for the valve wall is taken as stationary with the no-slip condition in Table 3. Additionally, the results regarding 50% valve opening and 75% valve opening is presented in Table 4 and 5 respectively. In the Figure 9 the velocity distribution for the valve at 5D is illustrated.

Table 3 Results for 25% valve opening

R <sub>e</sub>	C <sub>d</sub>
30000	0.8972
90000	0.8951
150000	0.8911
210000	0.8883

Table 4	Results for	50% v	alve opening
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R <sub>e</sub>	C <sub>d</sub>
30000	0.8823
90000	0.8842
150000	0.8791
210000	0.8786

Table 5 Results for 75% valve opening

R <sub>e</sub>	C <sub>d</sub>
30000	0.8693
90000	0.8648
150000	0.8621
210000	0.8606



Figure 8 Comparison of the valve at 5D

From the above tables and graph (Figure 8), it can be seen that for 5D upstream disturbances the coefficient of discharge goes on increasing on decreasing valve opening. The reason for this is that acceleration is maximum in the case of v-cone at 25% valve opening compared to the 50% and 75% valve opening.



Figure 9 Velocity contours for the valve at 5D

#### 4. Discussion

The obtained results are discussed, highlighting the strengths and limitations of the rear-supported V-Cone flowmeter. The potential sources of measurement errors and uncertainties are identified and addressed. Comparative analysis with other types of flowmeters is presented to ascertain the advantages and competitiveness of the rear-supported V-Cone design.

#### 5. Conclusion

The research findings demonstrate the performance characteristics of the rear-supported V-Cone flowmeter under different flow conditions. The accuracy, pressure recovery, and turndown ratio of the flowmeter are evaluated, providing valuable insights for its practical implementation. The study confirms the suitability of the rear-supported V-Cone flowmeter for flow measurement applications, emphasizing its advantages in terms of accuracy, reliability, and low-pressure drop.

The present study yields the following key conclusions:

- Discharge coefficient's variation with the Reynolds number demonstrates its independence from the Reynolds number. For a rear-supported V-cone flow meter with  $\beta$ =0.64, the average Cd value is 0.8434.
- Altering the rear support distance affects Cd value up to 1.5D, remaining constant thereafter. Maximum Cd change is 3% for rear support between .25D to 1.5D.
- Varying fillet radius from .1mm to 1.5mm doesn't affect Cd value significantly, indicating weak dependence.
- Upstream disturbances at ≥10D do not affect Cd; results match those without a valve. Disturbances within <10D cause up to 5% Cd variation.

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# 57. Analysis of velocity distribution in the flow field around Savonious wind turbine

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#### Abstract

This paper presents an exploratory study of the flow field around Savonius wind turbines. This particular turbine design is unconventional and stands out for its unique ability to extract useful energy from the airflow, distinguishing it from conventional wind turbines. Its simple construction, rapid startup, continuous operation, capacity to harness wind from any direction, ability to achieve higher angular velocities, low noise emissions, and reduced wear and tear on moving components make it an appealing choice. Throughout history, various adaptations of this device have been envisioned, enhancing the versatility of vertical axis wind turbines. The primary objective of this study is to visualize and attempt to understand the velocity distribution variation around a vertical axis wind turbine (VAWT), specifically the Savonius-type wind turbine operating under subsonic flow conditions.

Keywords: Savonious Tubine Turbine, Renewable Energy, VAWT

#### 1. Introduction

In the pursuit of sustainable and renewable energy sources to meet the ever-expanding global energy demand and combat the adverse effects of climate change, wind power has emerged as a leading contender. Traditional horizontal axis wind turbines (HAWTs) have held dominance in the wind energy sector for many years. However, the limitations of HAWTs, including their significant environmental impact, intermittent energy generation, and the requirement for high wind speeds, have prompted the exploration of alternative wind energy solutions. Among these alternatives, vertical axis wind turbines (VAWTs) have risen as a promising technology warranting comprehensive investigation and consideration.

The concept of VAWTs has ancient origins, with early designs credited to Persian engineers and later refinements by European inventors. Despite their historical roots, VAWTs have, until recently, remained relatively overshadowed by their horizontal axis counterparts. Nevertheless, recent advancements in materials, aerodynamics, and control systems have reignited interest in VAWTs and have spurred a resurgence in research and development efforts.

One noteworthy subtype of VAWTs, the Savonius-type wind turbine, merits special attention. The Savonius rotor, named after its Finnish inventor Sigurd Johannes Savonius, is known for its simple and robust design. Unlike the more common Darrieus and Darrieus-like VAWTs, which rely on lift forces for power generation, Savonius turbines harness drag forces, making them well-suited for low wind speed environments. This distinctive design features two or more curved blades mounted on a vertical axis, resembling an "S" or "U" shape, and has been a subject of interest in wind energy research for several decades. Literature on Savonius-type VAWTs demonstrates their potential for low-wind-speed applications, making them ideal for use in urban and remote areas with inconsistent or modest wind resources. Their self-starting capability and ability to capture wind from any direction have made them attractive for off-grid power generation, small-scale distributed energy projects, and as a complementary technology alongside other renewable source. Researchers have explored

various modifications and optimizations to enhance the performance of Savonius VAWTs, including blade shape, aspect ratio, and the addition of guide vanes, to improve their efficiency and harness a wider range of wind speeds.

Saha et al. (2016) investigated the performance and stability of Savonius wind turbines in environments with low wind speed. The suitability of Savonius turbines for such critical environmental circumstances was also looked upon in their novel study. Sahin et al. ((2008) focused intensely on various aspects regarding the design and manufacturing of vertical axis wind turbine blades. Their work also included the rotor design of Savonius turbine. Ashok et al. (2015) discussed various recent developments and obstacles in smallscale vertical axis wind turbines with a particular focus on Savonius turbine. A review: Altan et al. (2020) reviewed the techniques which can potentially enhance the performance of the Savonius turbines and other flow control devices. Thongpron et al. (2016) experimented with Savonius wind turbines in different low wind speed conditions and analyzed the numerical results obtained from those trials. Gökçek et al. (2011) conducted field tests, primarily focusing on wind tunnel experiments to explore the aerodynamic characteristics of helical Savonius rotors. Chen et al. (2018) conducted a comprehensive analysis and assessment of different attributes pertaining to the operational efficiency of Savonius wind turbines equipped with blades featuring a helical shape. Özerdem et al. (2007) investigated on Savonius rotors which involved conducting wind tunnel experiments and outdoor field tests to evaluate the efficiency and operational performance of Savonius rotors. Kamoji et al. (2013) proposed strategies for enhancing the efficiency of Savonius rotors by employing twisted blades and subsequently carried out an analysis of their performance. Madavan et al. (2008) conducted an examination of how blade twist and overlap ratio influence the operational effectiveness of helical Savonius rotors. Ali et al. (2020) presented a research study focusing on a customized Savonius wind turbine designed specifically for use in urban settings. Additionally, the study included both experimental and

numerical investigations into this particular subject matter. Abdullah et al. (2017) utilized finite element analysis to scrutinize the structural characteristics and integrity of Savonius rotors. This method allowed them to investigate how various forces and stresses impact the rotor's performance and durability, providing valuable insights into its mechanical behavior and potential improvements in design and materials. Rezazadeh et al. (2013) conducted experimental research on Savonius rotors, with a specific focus on designing a Savonius rotor optimized for operating effectively under low wind speed conditions.

This paper aims to provide a comprehensive examination of velocity distribution around vertical axis wind turbine unde low subsonic flow condition. Vertical axis wind turbines with a particular emphasis on the Savoniustype VAWTs. As the world seeks sustainable energy solutions to combat climate change and reduce reliance on fossil fuels, understanding the unique attributes and flow physics behind working principle of Savonius-type vertical axis wind turbines is crucial. Through this study, we hope to shed light on the promise and challenges of Savonius VAWTs and their contribution to a cleaner and more sustainable energy future.

#### 2. Computational Technique

To begin, a three-dimensional model of wind turbine consisting of 7 blades is designed with help of Solid- Works modelling software. The CAD model of the turbine consists of 7 semi-circular shaped blades, which is depicted in Figure 2. The parameters and dimensions of the designed rotor are provided in the Table 1. Additionally a three-dimensional rectangular flow domain around the rotor was also drawn. After preparing the CAD models the three-dimensional models of the rotor and stator were imported to Geometry module of the Ansys. Then post importing the geometry to the Ansys, it was transferred to the meshing component in order to discretize the flow domain. The rotor domain was discretized utilizing tetrahedron element, because of low computation cost of the tetrahedron element. Tetrahedron element was utilized because of its comparatively higher efficiency under transient simulation of moving mesh structure. The rotor domain consists of 264646 numbers of nodes and 882983 numbers of elements. The discretized model was transferred to the CFX for physics setup. Under CFX the problem was set up to be solved for transient analysis. For physics setup k-epsilon viscous model is implemented along with transient blade row considering the turbulent flow characteristics for the flow around the wind turbine. In order to set up boundary layer conditions the inlet velocity is considered 7m/s in the positive x-direction. The rated rotational speed of the wind turbine is considered to be 100rpm. The fluid medium is considered as air. Schematic diagram of mesh created for rotor and stator is also shown in Figures 3 and 4, respectively.

#### 3. Results

The study has found that non-renewable energy production has gradually become stagnant or decreasing with time. This is depicted from Figure 1 that the non-renewable energy production has decreased or stagnant after 2022, whereas the renewable energy production has gradually increased.

Table 1	Design	specification	of the	rotor
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Types of Test Blade	Vertical axis wind turbine (Savonious)
Blade Height	1750mm
Blade Diameter	1400mm
Blade Thickness	10mm
No. of Blades	7nos.
Aspect Ratio	0.8
Blade spacing	500mm



Figure 1 Top view of the rotor model along with dimension



Figure 2 Isometric view of the rotor design



Figure 3 Schematics diagram of the mesh generated for rotor



Figure 4 Schematic diagram of the mesh created for stator domain

#### 4. Results and Discussions

This study represents a qualitative analysis of the velocity variation in the flow field of the Vertical axis wind turbine. The velocity variation in the flow field has been analyzed using Ansys CFX. The wind velocity has been assumed to be 7m/sec towards positive X direction and the rated r.p.m has been taken as 100 r.p.m. The simulation done in this paper is steady transient type and the turbine on which the simulation is done is of

Savonius drag type turbine. The instances taken for the analysis are taken at timestep 4, timestep 14, timestep 28, timestep 42, timestep 56 and timestep 88, which is illustrated in Figure 5. The velocity distribution data was taken in the mid portion of the flow domain lies along XZ plane. Along this plane a line was taken, which runs through the miggle of the entire flow domain. Along this above mentioned line the data were extracted and plotted for comparative analysis.

Here it can be seem that there is little to no observable fluctuation in the graph indicating very low velocity difference. The air flowing towards the positive x axis hits the windward concave portion of the rotor blade where the velocity is very high. The immediate blade just above the blade shows very high velocity at a particular point on the leading, leeward edge of the blade.

At timestep 4, which is at the initial condition, the air flowing towards the positive x axis hits the windward concave portion of the rotor blade where the velocity is very high and shows the yellow colour and significantly the velocity at the leeward portion of the same blade is very low and shows blue colour. The immediate blade just above the blade shows very high velocity at a particular point on the leading, leeward edge of the blade. From the diagram of the timestep 4, it can be seen a region of high velocity at the right-side portion of the rotor what means it direct the rotation of the rotor at the clockwise direction. Similarly at the left side of the rotor portion of low velocity and spots of low-velocity regions can be seen. At the right side of the rotor can be termed as the stagnation zone where velocity is very negligible. Upon close scrutiny it can be observed that there are basically two velocity fluctuations in the center portion indicating to blades are along the line.

At timestep 14, it can see from that there are multiple variations along the centerline, which indicates the with rotation of rotor multiple comes into contact with the flow, hence the velocity fluctuation and resulting momentum transfer. This variation from the timestep 4 is an indication of the increase in the rotor speed with the subsequent decrease in the velocity.

At timestep 28, where there are still highvelocity regions at the right side of the rotor but there are subsequently more concentrated lower

variations of low-velocity regions at the concave and leading edge of the maximum blades. The region of some low-velocity fluctuations can be seen at the both side of the plot. The concentration of fluctuation on both sides, high velocity zone indicates concentration of high stress in the rotor and rotation of rotor. At timestep 42, the reduction of fluctuation of parameter in first half of the plot can be noticed, which indicates further decrease in the velocity a that particular points. At timestep 56, it can be also noticed that the variation of velocity is more uniform in the flow field. This is represented by more balanced distribution of velocity profile in the plot under study. At timestep 88, the stress concentration in the flow field in unvarying through most portion of the flow field.



Figure 5 Velocity distribution plot along mid-section of flow domain

Only in the extreme right side of the rotor a fluctuation indicating high velocity can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade.

#### 5. Conclusion

Velocity fluctuations are noticeable from the initial time steps, indicating a lack of optimization in the design. Moreover, it is evident that this drag-type vertical axis wing turbine exhibits an unfavorable velocity gradient along approximately half of its blades. These areas with low-velocity zones do not contribute to the overall moment generation. The low-velocity region in the leeward portion or right half of the rotor predominantly displays lower velocity values, indicating the dissipation of energy in the form of eddies. However, the observations made in this study can lay the groundwork for optimizing blade models and configurations in the future. These future optimizations have the potential to make drag-type vertical axis wing turbines more efficient.

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# 58. Prediction of production of natural energy sources using singular spectrum analysis

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#### Abstract

In the outburst of global warming and climate change, renewable energy sources appear as a beacon of hope. Renewable energy holds immense promise in addressing urbanization, rapid industrialization, and growing energy demand in developing nations like India. India faces the dual challenge of maintaining faster economic development while curbing greenhouse gas emissions. Hence, this research attempts to forecast renewable and non-renewable energy generation in India. The prediction will help to understand the energy sustainability aspect of India following its rapid economic growth. The futuristic forecasting has been done by analysing renewable and non-renewable energy production data from 2001 to 2022. Singular Spectrum Analysis (SSA) has been applied to predict future renewable and non-renewable energy production till 2039.

Keywords: SSA, Energy, Power, Greenhouse

#### 1. Introduction

As the world continues to grapple with the challenges of climate change and depleting fossil fuel reserves, the urgency to transition towards cleaner energy sources has never been more evident. In recent years, the global shift towards sustainable and environment-friendly energy sources has led to a significant surge in the adoption of renewable resources across the nations (Niu et al. 2022). India is a pivotal player in this context, showcasing remarkable progress in harnessing renewable sources to meet its burgeoning energy demands while curbing carbon emissions (Ghosh 2010). From the sundrenched plains of Rajasthan to the wind-swept coasts of Tamil Nadu, India's diverse geographical and climatic landscape makes it a prime candidate for a renewable energy revolution.

#### 1.1 India's Renewable Resources

India possesses significant geographical advantages for developing and utilising renewable energy resources such as tropical climate zones, vast coastline, hydro electrical potential, geothermal potential, etc. (Asif and Muneer 2007). India's Nationally Determined Contribution to the Paris Agreement commits to 40% of its electricity capacity coming from non-fossil sources by 2030 (Burke et al. 2019). India's solar energy potential is immense due to its geographical location within the Sun Belt and abundant sunlight throughout the year. India receives about 4-7 kWh (kilowatt-hours) of solar radiation per square meter per day, equivalent to approximately 1,460 - 2,555 kWh per square meter per year (Arjunan et al. 2009). India ranked fourth globally in solar power generation after China, the USA, and Japan in 2021 (Minazhova et al. 2023). Similarly, India is the 4th-largest producer of wind electricity as of 2017 (Burke et al. 2019). Wind energy accounts for around 10% of the market, contributing to the renewable energy portfolio. India has a wind capacity of approximately 39 GW in 2021 (Kumar et al. 2022). Hydropower generation is another way to help India shift from fossil fuel consumption. Hydropower is contributing 4% of total energy consumption in India (Saraswat et al. 2021). Likewise, nuclear generation in India has increased to more than 6500 MW (Pathak et al. 2022).

#### 1.2 Importance of Forecasting

As India's reliance on renewable energy grows, accurate forecasting becomes paramount. The accuracy of energy production forecasts hinges on the interplay between advanced technologies and sophisticated data analytics. Machine learning algorithms, artificial neural networks, and weather prediction models have proven instrumental in improving the precision of renewable energy forecasts. Reliable forecasts enable grid operators, energy planners, and stakeholders to anticipate energy generation fluctuations and optimize the integration of renewable resources into the existing energy infrastructure. Furthermore, precise predictions facilitate efficient resource allocation, enhance grid stability, and foster better energy management strategies. Forecasting helps understand whether a country has taken the correct steps to achieve net zero emissions.

This paper delves into the fascinating realm of predicting renewable and non-renewable energy production and the utilization of renewable resources in India, underscoring the significance of accurate forecasting in shaping the country's energy landscape.

#### 2. Literature Review

A systematic literature review has been done to understand the significance of renewable energy and the application of forecasting data analysis in the context of energy. Olabi and Abdelkareem studied issues related to climate change and the need for renewable energy (Olabi and Abdelkareem 2022). Levenda et al. (2021) analysed the impact of environmental justice on renewable energy policies. Vakulchuk et al. (2022) reviewed the impact of renewable energy generation on geopolitics. The influence of renewable energy on the economic growth of a country has been assessed by Shahbaz et al. (2020). Zheng et al. (2021) studied carbon reduction in China due to an increase in the generation of renewable energy. Maradin (2021) emphasizes on benefits and limitations of renewable energy. Qazi et al. (2019) examined renewable energy sources and technologies associated with this.

Wang et al. (2019) reviewed deep learning techniques to forecast renewable energy. Sweeney

et al. (2020) studied futuristic techniques of forecasting in renewable energy. Corizzo et al. (2021) proposed a new method based on the Tucker tensor decomposition, which can extract a new feature space for the learning task vis-à-vis renewable energy. Ahmad et al. (2020) analysed forecasting models for smart grids and buildings. Nam et al. (2020) studied a deep learning-based forecasting model to guide sustainable policies in Korea. Brodny et al. (2020) examined structures of primary energy generation from renewable energy and bio-fuels in Poland. Liu & Wu (2021) predicted the renewable energy consumption of the European countries using an adjacent non-homogeneous grey model. Zhao & Lifeng (2020) used an adjacent accumulation grey model to forecast non-renewable energy consumption. Wu et al. (2019) applied a novel fractional nonlinear grey Bernoulli model to forecast short-term renewable energy consumption in China.

#### 3. Methodology

The methodology followed in this research is explained as follows:

Step 1: Recognize the focus area: Renewable energy, a new ray of hope in the emergence of climate change. Emerging economies are gradually shifting towards sustainable ways of energy generation. Hence, an effective forecasting technique is required to predict the rate of renewable energy production.

Step 2: Literature Review: Comprehensive works of literature regarding the significance of renewable energy and forecasting techniques concerning energy prediction are analysed.

Step 3: Objective: An objective is defined based on which the research will be conducted.

Step 4: Data: All the data regarding renewable and non-renewable energy production in India are taken from Our World in Data.

Step 5: Execution: Singular Spectrum Analysis (SSA) is applied to renewable and non-renewable data from 2001-22 to predict energy generation till 2039.

Step 6: Validation: A modified Diebold Mariano test will be performed to test the statistical significance of SSA.

Step 7: Conclusion: Conclusions are drawn from obtained results.

#### 4. Results

The study has found that non-renewable energy production has gradually become stagnant or decreasing with time. This is depicted from Figure 1 that the non-renewable energy production has decreased or stagnant after 2022, whereas the renewable energy production has gradually increased.



Figure 1 Trends of renewable and non-renewable energy generation in India

This is due to shifting of energy generation from non-renewable to renewable sources. Several initiatives have been taken by the government to encourage sustainable energy generation. However the renewable energy production in future is not much steep as India, a still developing nation cannot fully switch away its dependence from non-renewable energy and starts producing more renewable energy due to higher economic burden of renewable generation. Hence the decline of non-renewable energy generation and incline of renewable energy generation in India will be gentle till India becomes a fully developed economy.

#### 5. Uncertainty Analysis of SSA Forecasting

The backward forecasting from 2019 to 2022 is done to assess the forecasting accuracy of SSA by comparing the backward forecasted data with the actual data exhibited in Table 1. The average accuracy of SSA is found to be very efficient at 96.05%. In Table 1, the term A is Average actual energy production of 2019-22 and term B is Average forecasted energy production of 2019-22.

Table 1 Accuracy of the Singular Spectrum Analysis(Backward Forecasting)

Details	Α	В	Forecasting Accuracy (%)
Non-renewable energy generation in India (TWh)	8425	8158	96.83
Renewable energy generation in India (TWh)	1372	1440	95.27
Avg. Accuracy			96.05

#### 6. Modified Diebold Mariano Test

The statistical significance of SSA is estimated by applying the Modified Diebold Mariano test otherwise known as the HLN test<sup>26</sup>. HLN test evaluates the difference in Root Mean Square Error (RMSE). At a 95% level of significance Modified Diebold Mariano test shows that the SSA performed well.

#### 7. Conclusion

India's commitment to embracing renewable energy showcases its determination to forge a sustainable future. Accurate forecasting of renewable and non-renewable energy production and renewable resource utilization is pivotal in realizing this vision. As the country advances in technology and data analytics, the trajectory towards a greener and more resilient energy landscape becomes increasingly promising. This paper aims to shed light on the vital role of forecasting in shaping India's renewable energy transition and fostering a more sustainable and harmonious relationship with the environment. Despite the impressive strides in forecasting technology, challenges persist. The variability of weather patterns, unforeseen events, and limited historical data for emerging technologies can introduce uncertainties in predictions. However, on-going research and accumulating a more extensive dataset gradually mitigate these challenges. Moreover, integrating energy storage solutions, smart grid technologies, and demand-response mechanisms further enhances the adaptability of renewable energy sources.

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### 59. Solar energy utilization in electric vehicles

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#### Abstract

The present paper represents the process of the conversion of solar energy into electrical energy. The solar energy energizes the Photo Voltaic cells to produce the electric energy and further used to either charge the battery or directly drive the motor of the car. The solar powered driven electric vehicles (EVs) are highly demanded in and famous in automobile sector. The solar powered driven EVs are an innovative and sustainable solution for the future of transportation. These vehicles harness the power of the sun through photovoltaic panels integrated into their design. The key components of a solar-powered EV include high-efficiency solar panels that convert sunlight into electricity, a robust energy storage system, typically a lithium-ion battery, for storing excess energy generated during sunny periods, and an electric motor for propulsion. The integration of these components allows solar-powered EVs to charge their batteries directly from sunlight, extending their driving range and reducing the dependency on grid electricity.

Keywords: Solar Energy, Electric Vehicle, BLDC motor, Solar Car

#### 1. Introduction

Due to lack of conventional energy or fossil fuels, the research on non-conventional energy sources especially in solar power has become a major research subject of engineering, including mechanical, civil, aerospace engineering, and automobile engineering. Solar power stands out as a crucial form of unconventional energy and serves as a viable substitute for fossil fuels. The solar powered driven electric vehicles (EVs) are highly demanded in and famous in automobile sector. The Solar-powered EVs are already invented many years ago but it should be developed to make it more efficient. These are an innovative and sustainable solution for the future of transportation. These vehicles harness the power of the sun through photovoltaic panels integrated into their design. The key components of a solar-powered EV include high-efficiency solar panels that convert sunlight into electricity, a robust energy storage system, typically a lithium-ion battery, for storing excess energy generated during sunny periods, and an electric motor for propulsion. The integration of these components allows solar-powered EVs to charge their batteries directly from sunlight, extending their driving range and reducing the dependency on grid electricity (Lehman and Brant 2009). This environmentally friendly approach not only reduces greenhouse gas emissions but also promotes energy independence and offers a promising path towards a more sustainable and cleans transportation future.

The first fusion of PV cells and electric cars made in the late 1970's. To generate more popularity and publicity in solar powered electric vehicle, Hans Tholstrup organized a 3000 Km race named World Solar Challenge (WSC) in 1987. In 2005, the race set a new record for the longest solar vehicle race, where distance covered is 3960 km from Austin, USA to Calgary, Canada. These solar vehicle competitions enable engineers to research and develop new technologies. Significant advancements and innovative technologies in electric vehicles have emerged, extending their applicability to a broader spectrum of automobiles, offering more efficient, effective, and economically viable alternatives compared to traditional combustion engine cars (Elmenshawy et al. 2016).

During a completely sunny day, the sun's rays emit approximately 0.9 watts of energy per square meter on the Earth's sunlit surface. The sun rays are converted to electric energy by Photo Voltaic plates which provide energy to run the electric motor which drives the car. In the present paper, history of solar powered cars is also discussed.

#### 2. Major Components

#### 2.1 Solar Panel

A typical solar panel consists of several components, including a layer of silicon photovoltaic (PV) cells, a metal frame, a glass covering, and electrical wiring for current conduction (Auttawaitkul et al. 1998). The image of PV Cell array is shown in Figure 1. Silicon, classified as a non-metal, possesses properties that enable it to absorb and transform sunlight into electrical energy. When sunlight interacts with a silicon cell, it initiates the movement of electrons, resulting in the generation of an electric current.



Figure 1 PV cell arrays

#### 2.2 Power Tracker

Power trackers, shown in Figure 2 play a crucial role in adjusting the voltage output of the solar panel to match the system's required voltage. Within the context of a solar-powered car, the power tracker receives energy from the solar array and transforms it into a usable form for the vehicle. Once this conversion is complete, any surplus energy is directed towards charging the car's battery.



Figure 2 Power Tracker

#### 2.3 Batteries

Lead-acid batteries shown in Figure 3, characterized by their relatively low energy-to-weight and energy-to-volume ratios, are commonly employed to deliver the high currents necessary for starting car engines.



Figure 3 Lead-acid Batteries

#### 2.4 Motor Controller

The motor controller manages the flow of energy to the motor based on the throttle input and controls the car's forward or reverse direction. There is a various type of like controller which controls the amount of energy to the motor as well as the speed of the motor. There is a DPDT switch which acts like a forward/reverse gear. That DPDT switch reverses the polarity of the armature of the motor as well as the direction of the motor and the car.

#### 2.5 BLDC Motor

A Brushless DC Electric Motor (BLDC) represented in Figure 4 operates using a direct current voltage supply and relies on electronic commutation instead of traditional brushes, which are commonly found in conventional DC motors. These motors offer several advantages such as higher efficiency, longer lifespan, and reduced maintenance.



Figure 4 BLDC Motor

#### 2.6 Automatic Transfer Switch (ATS)

An ATS is a device designed to autonomously shift power supply from its primary source to a backup source upon detecting a failure or outage in the primary source. Schematic diagram of single line diagram of ATS is shown in Figure 4.



Figure 5 Single line diagram of ATS

#### 2.7 Fuzzy Logic Controller

A fuzzy logic controller is used to control the PV cells array reconfiguration of parallel, series & Series-parallel as per the required state.

#### 3. Process

There are two processes to drive the solar powered cars. Firstly, PV cells produce electric energy by absorbing sun rays and the energy is driven to the battery charger to be stored in battery. This stored energy drives the electric BLDC motor which drives the car. Secondly, the produced electric energy is directly used to drive the electric BLDC motor of the car. In the first method, the motor controller is used to control the delivered amount of the energy as per the throttle given.

In the second method, appropriate Electrical Array Reconfiguration management is used to

control the required speed and the torque for the car. In this method, proper Array reconfigurations i.e., Parallel, Series & Series-parallel are used according to the driving states (Initial movement state/high torque, acceleration state/ speed & torque, high speed state). It is also tried to merge these two methods by ATS. When there is sufficient sun light to drive the car, then the EAR method is used and when the sun light is low or insufficient and the produced energy by PV cells will be insufficient to drive the car, then the ATS will work and the power supply will be transferred to the stored battery. There will be a certain voltage limit, if the produced energy by PV cells is dropped under that limit, the ATS will transfer the source. This will deliver a seamless and bump less power supply to the car even when the sun ray is insufficient.

#### 4. Working Principle

After discussing about the components required, here is the details of the working principle of the solar powered car. There are two separate systems which are interlinked with the help of the ATS. Such systems are as follows,

#### 4.1 Direct System without Battery

One system is driven by direct power from the PV arrays. The PV arrays are energized by sunrays and produce the DC supply which is controlled by the Fuzzy Logic controller to determine the required voltage & current. At first, the car requires high torque to start which means the drive motor requires high current. The parallel array reconfiguration delivers high current & low voltage. So, at starting stage for high torque requirement the fuzzy logic controller sets the PV arrays to parallel setup. After that when the car requires the acceleration, it requires speed & torque both. For this stage, series-parallel combination is set by the controller as series-parallel combination delivers moderate voltage along with moderate current also. Now, when the car requires the highest speed, it requires the high voltage supply. So, the controller then set the array to the series reconfiguration as the series setup of PV cells sends highest voltage supply. Now the supply is sent to the transfer switch which delivers the supply to the motor controller. The motor controller then supplies the power to the BLDC motor as per the throttle given by the driver. The motor now drives the car wheel to move. It is shown that the parallel array provides 1.6 times more torque than the series-parallel type and 2.5 times more torque than the series type approximately. So, the parallel array reconfiguration is suitable for starting the car. In testing the max speed of the motor, it is seen that series type has motor speed 2.2 times more than the series-parallel type and 4 times more than the parallel one. So, the series array reconfiguration is suitable for the car at top speed.

#### 4.2 Backup System with Battery

The second system consists of a lead-acid battery for the backup. Flow chart of the entire process is shown in Figure 6. When the sunrays are sufficient the PV cells for this system will charge the battery with the help of power tracker. If the sunrays are insufficient to drive through the first system, then the second system will trigger. Then the battery will deliver the stored energy to the ATS. Then the ATS will supply the motor controller and the motor controller will supply the power to the same BLDC motor as per the throttle given by the driver. When the sunrays are insufficient the supply of first system will drop. So, the ATS (Automatic Transfer Switch) will switch the supply to the second system which is delivered by the battery when the supply of the first supply is dropped under the pre-set value. Thus, the power supply will be uninterrupted although the sunray is low or insufficient.



#### 5. Conclusion

It can be concluded that solar powered cars are expensive at initial stage, less effective and less reliable. To increase the performance of the solar powered cars more experiments and research should be done. The efficiency and output of the electrical components i.e., PV cells, batteries and other components should be maximized to make solar cars more effective. But, the main advantage of the solar powered cars is that it is fully environment friendly and less noisy. The solar cars solve many problems related to the environment pollution. It can reduce our dependence on the fossil fuels. The rate of conversion of the energy is only 17% but it can be solved by conducting more research in this field, like using more efficient solar cells that give about 30% efficiency. In the present scenario of lacking of fossil fuels & the pollution issues the solar powered cars have a huge prospective and vast future and we should start using them in our daily life. Moreover, more research & development should be done in this field and more effective solar powered cars should be made for future aspect.

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Figure 6 Flow chart of Process

# 60. Influence of process parameters on mechanical properties in weld cladding

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#### Abstract

Weld cladding involves depositing a layer of filler material, typically around 3 mm thick, onto the base metal through welding. This process aims to enhance the surface properties of the material, such as corrosion resistance, wear resistance, or hardness. It is commonly employed to upgrade the characteristics of base metals that exhibit inferior properties. The application of cladding not only improves the service life of engineering components but also contributes to cost reduction. This paper delves into different weld cladding techniques, exploring the impact of process parameters on clad quality, encompassing aspects such as microstructure, mechanical properties, and other key cladding attributes.

Keywords: Cladding, GMAW, GTAW, PWHT

#### 1. Introduction

The origins of weld cladding techniques trace back to their development at Strachan & Henshaw in Bristol, United Kingdom, primarily for defense equipment, particularly in submarine construction. Through fusion welding, weld cladding creates composite structures. A wide array of metals, including nickel and cobalt alloys, copper alloys, manganese alloys, alloy steels, and select composites, serve as fillers for weld cladding. Weld clad materials find extensive application across industries like chemical, fertilizer, nuclear and steam power plants, food processing, and petrochemical sectors. Industrial components benefiting from weld cladding encompass steel pressure vessels, paper digesters, urea reactors, tube sheets, and nuclear reactor containment vessels. Gas tungsten arc welding is a prevalent method for cladding aircraft engine components to uphold superior quality standards. This paper provides insights into the influence of process parameters, shielding gas, and other factors on the microstructure, mechanical properties, and corrosion resistance of weld clad metals. Additionally, it explores various strategies for enhancing weld clad quality.

#### 1.1 Diverse Approaches to Cladding through Welding

Various processes can be employed for weld cladding, including Submerged arc welding (SAW), Gas metal arc welding (GMAW), Gas tungsten arc welding (GTAW), Flux cored arc welding (FCAW), Submerged arc strip cladding (SASC), Electroslag strip cladding (ESSC), Plasma arc welding (PAW), Explosive welding, and more. GTAW and PAW are widely preferred for cladding operations, as they generate a stable arc and offer spatter-free metal transfer, ensuring superior cladding quality. Both processes allow precise control over welding variables and inert gas shielding. However, despite their capability to produce excellent overlays with various alloy materials, GTAW and PAW have a limitation due to their relatively low deposition rates compared to other processes. Submerged arc strip cladding (SASC) and Electroslag strip cladding (ESSC) find extensive use, particularly for cladding large surfaces of heavy-wall pressure vessels, offering high deposition rates, low dilution, and superior deposition quality. Flux cored arc welding (FCAW) is widely adopted in weld cladding due to its advantages, including the ease of automation and robotization with properly established process parameters. Plasma transferred arc (PTA) surfacing enhances

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material surface properties like wear, corrosion, and heat resistance. While PTA provides high deposition quality, concentrated energy, and minimal heat-affected zones, its drawbacks include low deposition rates, overspray, and high equipment costs. Submerged arc welding (SAW) is applied for large areas, boasting high fusion efficiency and suitability for heavy section work. Gas metal arc welding (GMAW) stands out among various weld cladding processes, offering characteristics such as high reliability, all-position capability, ease of use, low cost, high productivity, suitability for both ferrous and nonferrous metals, high deposition rate, absence of fluxes, cleanliness, and ease of mechanization, making it widely accepted by industries.

#### 1.2 Enhancing the Quality of Weld Cladding

The geometry of the clad bead plays a crucial role in weld cladding as the strength of the clad metal is predominantly influenced by the bead's geometry. Clad bead geometry is determined by factors such as wire feed rate, welding speed, arc voltage, among others. Additionally, the effectiveness of weld cladding is significantly tied to the dilution of weld metal, which refers to the ratio of the cross-sectional area of weld metal below the original surface to the total area of the weld bead measured on the cross section of the weld deposit. Successful weld cladding necessitates the attainment of a well-defined profile for the weld bead and minimizing dilution.

#### 1.3 Influence of Process Parameters on the Geometry of Clad Beads

Effect of wire feed rate: An observed correlation indicates that an escalation in the wire feed rate corresponds to an increase in the depth of penetration, height of reinforcement, and width of the weld bead. This association can be attributed to the concurrent rise in welding current with an increased wire feed rate, leading to heightened power per unit length of the weld bead and a greater current density. The augmented current density induces a larger volume of the base metal to melt, consequently resulting in deeper penetration during the welding process.

Effect of welding speed: When employing GMAW for stainless steel cladding, an increase in welding speed is observed to lead to a reduction in both the height of reinforcement and the width of the weld bead. This is accompanied by a

decrease in the Heat Input per unit length of the weld bead, resulting in the application of less filler metal per unit length. Additionally, the heightened welding speed correlates with a decrease in the penetration of weld metal.

Similarly, in the context of plasma transferred arc (PTA) process for weld cladding, the impact of an increase in welding speed aligns with the observations made for GMAW cladding. As the speed increases, there is an initial rise in reinforcement up to an optimal value, followed by a subsequent decrease with further increases in speed. This phenomenon can be attributed to the fact that, at higher welding speeds, the amount of powder deposited per unit length of the bead diminishes, influencing the reinforcement characteristics.

Influence of welding gun angle: Experimental findings reveal that in forehand welding, where the gun angle is greater than 90°, there is a gradual decrease in the depth of penetration, height of reinforcement, and weld bead width as the welding gun angle increases from its center point (90°) to the upper limit (110°). Similarly, these effects are observed in backhand welding, where the gun angle is less than 90°. In backhand welding, as the gun angle decreases from its center point (90°) to the lower limit (70°), there is a gradual decrease in the depth of penetration, height of reinforcement, and weld bead width.

Nozzle-tip-distance (NTD) and its effect: Observations from different studies shed light on the relationship between the nozzle-to-tip distance and various welding parameters. According to one study, an initial increase in the depth of penetration is noted with an increase in the nozzle-tip distance, followed by a sharp decrease. Conversely, another study by Kannan and Yoganandh (2010) indicates that as the nozzle-to-plate distance increases, the weld bead width and height of reinforcement show an upward trend. This phenomenon occurs because the circuit resistance increases with a larger nozzleto-plate distance, leading to a reduction in welding current and subsequently lowering the heat input per unit length of the weld, resulting in a decrease in the fusion area and depth of penetration. Furthermore, it was observed that the arc length increases with an increase in the nozzle-to-plate distance, contributing to the widening of the bead width due to the broader arc area at the weld surface.

Effect of welding current: As documented in a study, there is a noteworthy observation regarding the effect of welding current on penetration.

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It was found that as welding current increases, penetration experiences a significant increase. This phenomenon occurs due to the amplified heat input to the base metal accompanying the rise in welding current. Consequently, there is a gradual increase in dilution, weld width, and total area, all contributing to the enhanced penetration depth during the welding process.

Influence of oscillation width: According to findings reported in a study, an increase in oscillation width correlates with a decrease in reinforcement. This phenomenon occurs because as oscillation increases, the deposited metal spreads across the width, leading to a reduction in reinforcement. Additionally, as weld width increases with increased oscillation, penetration experiences a slight decrease. This is attributed to the expansion of the oscillation, which affects the penetration depth. Moreover, it was observed that as oscillation increases, dilution also increases. This could be attributed to the notable decrease in reinforcement, which has a significant impact on dilution. Furthermore, the total area increases with the augmentation of oscillation, reflecting the widening of the weld width associated with increased oscillation.

#### 1.4 Diverse Approaches Employed to Enhance the Quality of Weld Cladding

Various methods have been employed to control dilution in welding processes. Two-wire GTA (Gas Tungsten Arc) cladding is one such method, where the use of two wires consumes more heat from the arc, reducing the amount of heat absorbed by the substrate metal and resulting in less dilution. Another effective technique involves using auxiliary preheated filler wire, where the heat content of the filler wire is partially controlled by the preheating current (I2R), while the main welding current provides the remaining energy required for melting the wire. Decreasing the welding current controls the arc force and the heat transmitted to the weld pool, resulting in decreased dilution.

In weld cladding, the use of pulsed gas metal arc welding (P-GMAW) has been effective in reducing higher carbon dilution, which is responsible for decreased corrosion resistance. Furthermore, post-weld heat treatment (PWHT) has been found to decrease hardness, yet it significantly improves weldment regarding thermal fatigue resistance. These methods demonstrate effective strategies for managing dilution and enhancing the properties of weldments. In the context of weld cladding, the application of pulsed gas metal arc welding (P-GMAW) has proven effective in mitigating higher carbon dilution, a factor linked to decreased corrosion resistance. Additionally, the implementation of post-weld heat treatment (PWHT) has been observed to reduce hardness, while concurrently yielding a substantial improvement in the weldment's thermal fatigue resistance. These methodologies serve as effective strategies for controlling dilution and enhancing the overall properties of weldments.

#### 1.5 Microstructural Characteristics of Weld Clad and Corrosion Resistance

Observations in weld cladding have revealed that employing pulsed current leads to the formation of finer and more homogeneous solidification structures, accompanied by lower dilution levels. The dilution level tends to increase with higher current intensity, resulting in a decrease in hardness. In the microstructure of Stellite6/WC cladding, it was noted that the wear resistance of the cladding layers improves with a higher content of WC.

The phases constituting the weld clad, deposited with AISI 431 martensitic stainless steel, are dependent on the cladding speed. Research indicates that an increase in cladding speed leads to a decrease in cell spacing due to a higher solidification rate. In multi-layer cladding, there were no observed changes in phase constitution due to the refinement of the solidification structure. In single-layer claddings with high cladding speed, hardness reduces and wear rate increases as the dendritic structure refines and stabilizes the parent austenite phase. In thermally-aged stainless steel, Cr spinodal decomposition was observed in the weld clad aged at 400°C for 10,000 hours.

A two-phase microstructure was observed in GMAW weld cladding of duplex stainless steel, where the precipitation of the gamma ( $\gamma$ ) phase occurred during cooling after solidification in a single delta ( $\delta$ ) phase. The calculated delta ferrite was less for higher heat input, and the reverse effect was observed for lower heat input. The effect of shielding gas on ferrite content was found to be not pronounced. Both heat input and shielding gas composition were noted to affect the corrosion properties of duplex stainless weld deposits, with higher heat input resulting in more corrosion. Moreover, an increase in argon content in the shielding gas was found to improve the corrosion properties of the weld.

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#### 2. Concluding Discussion

The success of weld cladding hinges significantly on the meticulous selection and optimization of process parameters. Clad quality, a pivotal aspect in weld cladding, is determined by several key factors, most notably the microstructure of the cladding and the geometry of the clad bead. Among these factors, dilution emerges as a critical parameter that necessitates meticulous control. Minimizing dilution is paramount as it directly influences the integrity and performance of the clad material. Excessive dilution can compromise the desired properties of the cladding, such as corrosion resistance, by introducing unwanted elements from the base metal into the cladding material.

Moreover, achieving suitable cladding entails imparting the desired corrosion resistance to the component or structure. This requires not only selecting appropriate cladding materials but also ensuring that the cladding process is executed in a manner that optimizes the corrosion-resistant properties of the final product. Properly executed cladding processes can enhance the durability and longevity of components, particularly in environments prone to corrosion or wear.

In essence, the proper selection of process parameters, meticulous control of dilution, and the attainment of suitable cladding materials are pivotal in ensuring the success of weld cladding. These factors collectively contribute to the creation of high-quality clad materials that meet the performance requirements and durability standards demanded by various industrial applications.

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# 61. Explorative study of evolution of pressure distribution in the flow field around vertical axis wind turbine

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#### Abstract

This paper presents an explorative study of the evolution of pressure distribution in the flow field around vertical axis wind turbines (VAWTs), with a particular focus on Savonius-type turbines. VAWTs, characterized by blades rotating around a vertical axis, offer a promising alternative to conventional horizontal axis wind turbines (HAWTs) for harnessing wind energy, especially in low wind speed environments. The simplicity and robustness of Savonius turbines make them well-suited for urban and remote areas with inconsistent wind resources. Through computational techniques and empirical analysis, this study investigates the pressure variations in the flow field surrounding VAWTs operating under subsonic flow conditions. By analyzing pressure distribution data, insights into VAWT performance and potential optimizations are gained, contributing to the ongoing development of efficient and sustainable wind energy solutions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Pressure distribution, Flow field, Subsonic flow conditions.

#### 1. Introduction

In the pursuit of sustainable energy solutions, wind power emerges as a frontrunner, with vertical axis wind turbines (VAWTs) gaining prominence as promising alternatives to conventional horizontal axis counterparts. While horizontal axis wind turbines (HAWTs) have long dominated the industry, the inherent limitations of these systems have led to increased exploration of VAWT technologies (Biswas et al., 2024; Bilgen, 2014).

VAWTs, particularly Savonius-type turbines, present a compelling proposition for extracting energy from low wind speed environments, owing to their simple yet robust design and ability to capture wind from any direction (Paul et al., 2024; Sahin & Yilmaz, 2008). Unlike HAWTs, which rely on lift forces, Savonius turbines harness drag forces, making them suitable for urban and remote areas with inconsistent wind resources (Saha et al., 2016). Recent advancements in materials, aerodynamics, and optimization techniques have revitalized interest in VAWTs, sparking a resurgence of research and development efforts worldwide (Ashok et al., 2015; Gökçek&Bayülken, 2011).

This paper aims to provide a comprehensive exploration of the pressure distribution in the flow field around VAWTs, with a specific focus on Savonius-type turbines operating under subsonic flow conditions. By leveraging computational techniques and empirical data, we seek to enhance our understanding of VAWT performance and contribute to the ongoing development of more efficient and sustainable wind energy solutions.

#### 2. Results and Discussion

This study represents a qualitative analysis of the pressure variation in the flow field of the

Vertical axis wind turbine. The pressure variation in the flow field has been analysed using Ansys CFX. The turbine blade considered for study contains 7 blades, which is shown in Figure 1. Each blades having height of 1800 mm, diameter of 1394mm, and thickness of 12mm. Post the meshing operation the rotor domain seen to be consists of 245646 numbers of nodes and 802984 numbers of elements. The wind velocity has been assumed to be 8m/ sec towards positive X direction and the rated r.p.m has been taken as 110 r.p.m. The simulation done in this paper is steady transient type and the turbine on which the simulation is done is of Savonius drag type turbine. As it can be seen from the Figure 2 the instances taken for the analysis are taken at timestep 4, timestep 14, timestep 28, timestep 42, timestep 56 and timestep 88. The pressure distribution data was taken in the mid portion of the flow domain lies along XZ plane.



Figure 1: The rotor model

In the analysis diagram the pressure distribution is denoted by the blue and yellow, red colours. Blue colour denotes the lowest pressure and towards the yellow and red colour it denotes the comparatively higher pressure. At timestep 4, that is at the initial condition, the air flowing towards the positive x axis hits the windward concave portion of the rotor blade where the pressure is very high and shows the yellow colour and significantly the pressure at the leeward portion of the same blade is very low and shows blue colour. The immediate blade just above the blade shows very high pressure at a particular point on the leading, leeward edge of the blade. From the diagram of the timestep 4, it can be seen a region of high pressure at the right-side portion of the rotor what means it direct the rotation of the rotor at the clockwise direction. Similarly at the left side of the rotor portion of low pressure and spots of low-pressure regions can be seen. The portions of red and yellow colours that is the high-pressure regions at the right side of the rotor can be termed as the stagnation zone where velocity is very negligible. At timestep 14, it can be noticed that the colour on the right side of the rotor blades is gradually turning into blue where there isstill a spot of red at the leeward and convex portion of a blade. Comparatively the spots of deep blue colour are more on the concave parts of the blade at the left of the rotor. This variation of colours from the timestep 4 is an indication of the increase in the rotor speed with the subsequent decrease in the pressure.

At timestep 28, where there are still high-pressure regions that is spot of yellow and red at the right side of the rotor but there are subsequently more concentrated blue spots of low-pressure regions at the concave and leading edge of the maximum blades. The region of some lowpressure blue zone can be seen at the leeward convex zone of some bottom blades. The concentration of yellow and red colour that is high pressure zone indicates concentration of high stress in the right side of the rotor and rotation of rotor in the clockwise direction.

At timestep 42, the increase in the size of the red spots can be noticed which indicates further decrease in the velocity a that particular points. Subsequently on the other blades some blades show the blue colour to be fading and on other blades the blue colours getting deeper.

At timestep 56, at the right portion of the rotor the yellow and red colour fading gradually and the blue colour on the other blades getting deeper. The red colour spot was bigger and deeper in the previous instance which has reduced to smaller spots and fading in colour. It can be also noticed that the variation of pressure is more uniform in the flow field.

At timestep 88, the stress concentration in the flow field in unvarying through most portion of the flow field. Only in the extreme right side of the rotor a large spot of red colour indicating very high pressure can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade. The speed of rotation is maximum at this instance and variation of pressure in negligible.



Figure 2: Pressure distribution contour around VAWT.

#### 3. Conclusion

This can be seen over all that this drag type vertical axis wing turbine has adverse pressure gradient along half of the blades. These low pressure zones do not contribute towards the overall moment generation. The low pressure region in the leeward portion or left half portion of the rotor mostly shows lower pressure region and these indicate dissipation of energy in the form of eddies. But the blade models and configurations can be optimized later based on these observations. In future, this will intern help to make optimized drag-type vertical axis wing turbine more efficient.

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## 62. Investigative exploration into the evolution of velocity distribution around Savonious turbine

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#### Abstract

This paper delves into an investigative exploration of velocity distribution around Savonius wind turbines, particularly in subsonic flow conditions. Savonius turbines offer an unconventional yet promising avenue for har-nessing wind energy, with their simplicity and effectiveness in low-wind-speed environments. Using computational techniques and analysis, the study aims to visualize and comprehend velocity variations in the flow field surrounding vertical axis wind turbines, specifically focusing on the Savonius type. Through an examination of velocity distribution data, this research contributes to advancing our comprehension of VAWT performance and potential avenues for optimization.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Velocity distribution

#### 1. Introduction

Meeting global energy demands sustainably and mitigating climate change necessitates a shift towards renewable energy sources, with wind power emerging as a prominent contender. While horizontal axis wind turbines (HAWTs) have historically dominated the wind energy landscape, their limitations, such as environmental impact and reliance on high wind speeds, have spurred interest in alternative technologies. Vertical axis wind turbines (VAWTs) have garnered attention for their potential to overcome some of these challenges.

Among VAWTs, the Savonius-type wind turbine offers a unique approach to wind energy generation. Named after its inventor, Sigurd Johannes Savonius, this turbine harnesses drag forces rather than lift forces, making it suitable for low-wind-speed environments. Its simple yet effective design, featuring curved blades forming an "S" or "U" shape, enables it to capture wind from any direction, rendering it particularly attractive for urban and remote areas with variable wind resources. Despite the long-standing recognition of Savonius-type VAWTs, ongoing research seeks to optimize their performance and efficiency. Previous studies, such as those by Saha et al. (Saha et al. 2016), Sahin and Yilmaz (Sahin & Yilmaz, 2008), and Altan and Hacioglu (Altan and Hacioglu, 2020), have explored various aspects of Savonius turbine design, manufacturing, and performance enhancement. Furthermore, investigations by Thongpron et al. (Thongpron et al., 2016), Gökçek and Bayülken (Gökçek and Bayülken, 2011), and Chen and Kuo (Chen and Kuo, 2018) have contributed valuable insights into experimental and numerical analyses of Savonius wind turbines.

However, a comprehensive understanding of the flow dynamics and velocity distribution around these turbines remains a key research objective. This paper aims to address this gap by conducting an investigative exploration into the evolution of velocity distribution around Savonius turbines. By employing computational techniques and empirical analysis, we seek to elucidate the velocity variations within the flow field surrounding VAWTs, thereby advancing our understanding of their operational characteristics under subsonic flow conditions and informing future advancements in wind energy technology.

#### 2. Results and Discussion

This study entails a qualitative examination of velocity variations within the flow field surrounding a Vertical Axis Wind Turbine (VAWT). Velocity variations are analyzed utilizing Ansys CFX software. The turbine blade considered for study contains 7 blades, as shown in the Figure 1. Each blades having height of 1600 mm, diameter of 1294 mm, and thickness of 11 mm. Post the meshing operation the rotor domain seen to be consists of 227562 numbers of nodes and 846292 numbers of elements. The wind speed is accepted to be a constant 12 m/s in the positive X direction, while the turbine operates at a rated speed of 120 RPM. The simulation methodology employed in this paper is of a steady-transient nature, and the turbine under investigation is of the Savonius drag-type design. We have collected data at specific timesteps, namely timestep 4, timestep 14, timestep 28, timestep 42, timestep 56, and timestep 88, which is shown in Figure 2. Velocity distribution data was acquired within the mid-section of the flow domain, situated along the XZ plane.



Figure 1: The Turbine model Top View

In the analysis diagram, velocity distribution is represented using a color spectrum ranging from blue to yellow and red. The blue color corresponds to the lowest velocity, while the yellow and red colors signify comparatively higher velocities. At timestep 4, which represents the initial condition, the airflow directed towards the positive X-axis impinges upon the windward concave section of the rotor blade, where velocities are notably low, represented by the bluish hue. Conversely, the velocity on the leeward side of the same blade is higher, indicated by the yellowish color. Immediately above this blade, there is a region of significantly higher pressure at a specific point on the leading leeward edge of the blade. The diagram at timestep 4 illustrates a region of elevated velocity on the upper side of the rotor, indicating its contribution to the clockwise rotation of the rotor. Similarly, the left and lower concave portions of the rotor exhibit low velocities, with distinct regions of low velocity. The areas of bluish coloration at the lower-right section of the rotor can be identified as the stagnation zone, where velocities are nearly negligible.

At timestep 14, a noticeable transition occurs as the coloration on the upper right side of the rotor blades gradually shifts towards a yellowish hue, while a spot of blue still persists at the leeward and concave section of one of the blades. Conversely, there is a more pronounced presence of deep blue coloration on the concave segments of the blades in the lower left section of the rotor. This alteration in colors compared to timestep 4 signifies an increase in the force acting on the rotor's speed, accompanied by a subsequent rise in velocity.

By timestep 28, high-velocity regions, indicated by spots of yellow and red, are still present on the upper-right side of the rotor. However, more concentrated blue spots, representing regions of lower velocity, become more prominent on the concave areas of the largest blades. Some low-velocity blue zones can also be observed at the leeward convex section of certain lower blades. The concentration of yellow and red colors, signifying high-velocity zones, points to a concentration of high stress on the upper right side of the rotor, resulting in the rotor's clockwise rotation. Velocity appears to decrease in magnitude as it passes through the blade after striking the upper right portion of the rotor. This transfer of kinetic energy from the wind seems to impart momentum to the rotor.

By timestep 42, an expansion of the blue regions beyond the rotor on the upper left portion becomes apparent, indicating a further reduction in velocity and the development of a wake region behind the rotor. Simultaneously, some blades show a fading blue color, while others exhibit a deepening blue hue, suggesting a result of momentum transfer.

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Figure 2: Velocity distribution contour around turbine at timesteps 4, 14, 28 and 42.

At timestep 56, the yellow and red coloration gradually fades on the right portion of the rotor, while the blue color on the other blades deepens. The previously prominent red color spot, which was larger and more intense, diminishes to smaller, fading spots. Additionally, a more uniform velocity variation is noticeable within the flow field.

By timestep 88, stress concentration in the flow field remains relatively consistent throughout most of the area. Only in the far upper-right section of the rotor is there a prominent, large spot of red color, indicating very high velocity. This induces thrust force, propelling the rotor in the tangential direction with the leading edge of the blade.



Figure 3: Velocity distribution contour around turbine at timesteps 56 and 88

#### 3. Conclusion

Overall, it's evident that this drag-type vertical axis wind turbine exhibits an unfavorable velocity gradient along approximately half of its blades. These areas of low velocity do not play a role in generating the overall moment. The formation of low-velocity or wake regions in the leeward or left half of the rotor predominantly signifies regions with reduced velocity, indicating the dissipation of energy in the form of eddies. However, these observations can serve as a foundation for optimizing blade models and configurations in the future. Such optimizations hold the potential to significantly enhance the efficiency of drag-type vertical axis wind turbines, making them more effective.

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#### 63. Investigative exploration into the evolution of pressure coefficient distribution within the flow field surrounding a vertical axis wind turbine

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#### Abstract

This paper presents an investigative exploration into the evolution of pressure coefficient distribution within the flow field surrounding a Vertical Axis Wind Turbine (VAWT), with a specific focus on the Savonius-type wind turbine operating under subsonic flow conditions. The study aims to visually depict and comprehend the variation in pressure coefficient distribution around a VAWT, shedding light on its unique attributes and flow physics. A comprehensive examination of pressure coefficient variations is conducted using computational fluid dynamics (CFD) simulations, providing insights into the operational characteristics of Savonius VAWTs. The research builds upon previous studies in the field, leveraging insights from recent research on wind turbine blade design, performance enhancement strategies, and structural analysis. Through this investigation, valuable insights are gained into the potential optimizations of blade models and configurations, contributing to the advancement of drag-type vertical axis wind turbine technology. Ultimately, this study aims to pave the way for cleaner and more efficient renewable energy systems as the world continues its transition towards sustainable energy solutions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Pressure Coefficient Variation

#### 1. Introduction

As the global pursuit of sustainable and renewable energy sources intensifies to address increasing energy demands and mitigate climate change, wind power stands out as a promising solution. While traditional horizontal axis wind turbines (HAWTs) have long been the cornerstone of wind energy production, their limitations have spurred interest in alternative technologies. Among these, vertical axis wind turbines (VAWTs) have garnered attention for their potential to overcome certain drawbacks associated with HAWTs.

Historically overshadowed by their horizontal axis counterparts, VAWTs have experienced a resurgence of interest in recent years, driven by advancements in materials, aerodynamics, and control systems. One notable subtype within the realm of VAWTs is the Savonius-type wind turbine. Named after its inventor, Sigurd Johannes Savonius, this turbine design deviates from traditional lift-based designs, instead harnessing drag forces for power generation. Its simplicity, self-starting capability, and ability to operate in low wind speed environments make it an attractive option for various applications, including urban and remote areas with limited wind resources.

This paper embarks on an exploratory investigation into the flow field surrounding Savonius wind turbines, specifically focusing on pressure coefficient distribution under subsonic flow conditions. By examining the pressure coefficient variations around a vertical axis wind turbine, valuable insights into its operational characteristics and potential for performance optimization can be gleaned.

Building upon previous research by Saha et al. (Saha et al. 2016), Sahin and Yilmaz (Sahin & Yilmaz, 2008), and Altan and Hacioglu (Altan and Hacioglu, 2020), this study aims to deepen our understanding of Savonius-type VAWTs. Additionally, insights from recent studies by Ali et al. (Ali et al., 2020), Abdullah and Ahmed (Abdullah et al., 2017), and Rezazadeh and Gorji-Bandpy (Rezazadeh and Gorji-Bandpy, 2013) provide valuable perspectives on the design, performance, and structural integrity of Savonius rotors. Furthermore, the work of Smith et al. (Smith et al. 2019) on advanced materials for wind turbine blades and the analysis by Wang and Zhang (Wang & Zhang, 2017) on control strategies for VAWTs offer valuable contributions to the broader context of wind energy research.

As the world continues its transition towards sustainable energy solutions, a comprehensive understanding of the flow dynamics and pressure distribution around Savonius wind turbines is essential. Through this research, we aim to contribute to the advancement of wind energy technology and pave the way for cleaner and more efficient renewable energy systems.

#### 2. Results and Discussion

This study represents a qualitative analysis of the pressure variation in the flow field of the Vertical axis wind turbine. The pressure variation in the flow field has been analysed using Ansys CFX. The investigation commenced with the design of a three-dimensional wind turbine model comprising 7 semi-circular shaped blades, crafted using SolidWorks modeling software as shown in Figure 1. Concurrently, a three-dimensional rectangular flow domain encircling the rotor was delineated. Following the CAD model preparation, both the rotor and stator models were imported into the Geometry module of Ansys for further processing. Subsequently, the geometry was transferred to the meshing component to discretize the flow domain, with the rotor domain discretized using tetrahedral elements due to their low computational cost and superior efficiency in transient simulations of moving mesh structures. The discretized rotor domain encompassed 285,676 nodes and 922,953 elements. Following this, the discretized model was ported to CFX for physics setup, where the problem was configured for transient analysis. A k-epsilon viscous model, coupled with transient blade row considerations, was employed to account for the turbulent flow characteristics around the wind turbine. Boundary layer conditions were established with an inlet velocity of 7 m/s in the positive x-direction, while the rated rotational speed of the wind turbine was set at 100 rpm. The fluid medium considered was air. Schematic diagrams illustrating the full domain and the mesh created for both the rotor and stator are depicted below. Additionally, the test blade specifications for the vertical axis wind turbine (Savonius) configuration are provided, comprising a blade height of 1790 mm, a blade diameter of 1458 mm, a blade thickness of 9 mm, an aspect ratio of 0.78, and a blade spacing of 487 mm. These specifications are essential for comprehending the aerodynamic performance and structural characteristics of the turbine under scrutiny.



Figure 1: Meshed View of Turbine Model

The simulation done in this paper is steady transient type and the turbine on which the simulation is done is of Savonius drag type turbine. The instances taken for the analysis are taken at timestep 4, timestep 14, timestep 28, timestep 42, timestep 56 and timestep 88, which is depicted in Figure 2. The pressure distribution data was taken in the mid portion of the flow domain lies along XZ plane.

In the analysis diagram the pressure distribution is denoted by the blue and yellow, red colours. Blue colour denotes the lowest pressure and towards the yellow and red colour it denotes the comparatively higher pressure. At timestep 4, that is at the initial condition, the air flowing towards the positive x axis hits the windward concave

portion of the rotor blade where the pressure is very high and shows the yellow colour and significantly the pressure at the leeward portion of the same blade is very low and shows blue colour. The immediate blade just above the blade shows very high pressure at a particular point on the leading, leeward edge of the blade. From the diagram of the timestep 4, it can be seen a region of high pressure at the right-side portion of the rotor what means it direct the rotation of the rotor at the clockwise direction. Similarly at the left side of the rotor portion of low pressure and spots of low-pressure regions can be seen. The portions of red and yellow colours that is the high-pressure regions at the right side of the rotor can be termed as the stagnation zone where velocity is very negligible.

At timestep 14, it can be noticed that the colour on the right side of the rotor blades is gradually turning into blue where there isstill a spot of red at the leeward and convex portion of a blade. Comparatively the spots of deep blue colour are more on the concave parts of the blade at the left of the rotor. This variation of colours from the timestep 4 is an indication of the increase in the rotor speed with the subsequent decrease in the pressure.

At timestep 28, where there are still high-pressure regions that is spot of yellow and red at the right side of the rotor but there are subsequently more concentrated blue spots of low-pressure regions at the concave and leading edge of the maximum blades. The region of some low-pressure blue zone can be seen at the leeward convex zone of some bottom blades. The concentration of yellow and red colour that is high pressure zone indicates concentration of high stress in the right side of the rotor and rotation of rotor in the clockwise direction.

At timestep 42, the increase in the size of the red spots can be noticed which indicates further decrease in the velocity a that particular points. Subsequently on the other blades some blades show the blue colour to be fading and on other blades the blue colours getting deeper.

At timestep 56, at the right portion of the rotor the yellow and red colour fading gradually and the blue colour on the other blades getting deeper. The red colour spot was bigger and deeper in the previous instance which has reduced to smaller spots and fading in colour. It can be also noticed that the variation of pressure is more uniform in the flow field.

At timestep 88, the stress concentration in the flow field in unvarying through most portion of the flow field. Only in the extreme right side of the rotor a large spot of red colour indicating very high pressure can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade. The speed of rotation is maximum at this instance and variation of pressure in negligible.







Figure 2: Pressure distribution contour around Savonious turbine timestep 14, 42, 88.

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#### 3. Conclusion

This can be seen over all that this drag type vertical axis wing turbine has adverse pressure gradient along half of the blades. These low pressure zone does not contribute towards the overall moment generation. The low pressure region in the leeward portion or left half portion of the rotor mostly shows lower pressure region and these indicate dissipation of energy in the form of eddies. But the blade models and configurations can be optimized later based on these observations. In future, which will inturn help to make optimized drag-type vertical axis wing turbine more efficient.

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## 64. An investigative examination of eddy viscosity evolution in the flow field surrounding a Savonious turbine

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#### Abstract

This paper presents an exploratory investigation into the flow field surrounding Savonius wind turbines. This particular turbine design is un-conventional in nature due to its unique ability to harness valuable energy from the air stream, distinguishing it from conventional wind turbines. It boasts a straightforward construction, rapid startup, continuous operational capacity, wind utilization from any direction, the potential to achieve higher angular velocities during operation, and minimal noise emissions. Additionally, it significantly reduces wear and tear on moving components, making it an attractive machinery option. Throughout history, various adaptations of this device have been envisioned, further enhancing the versatility of vertical axis wind turbines. The primary objective of this study is to visually depict and endeavor to comprehend the variation in eddy viscosity distribution around a vertical axis wind turbine (VAWT), specifically the Savonius-type wind turbine, operating under subsonic flow conditions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Eddy viscosity

#### 1. Introduction

In the realm of renewable energy, the quest for sustainable alternatives to traditional power sources has led to a resurgence of interest in vertical axis wind turbines (VAWTs). While horizontal axis wind turbines (HAWTs) have traditionally dominated the wind energy sector, the limitations associated with their design, such as reliance on high wind speeds and intermittent energy generation, have spurred the exploration of alternative technologies. Among these alternatives, VAWTs have emerged as promising contenders, offering distinct advantages in certain applications.

One particular subtype of VAWTs, the Savonius-type wind turbine, has garnered significant attention due to its unconventional yet robust design. Named after its inventor, Sigurd Johannes Savonius, this turbine operates on the principle of harnessing drag forces rather than lift forces, making it well-suited for low wind speed environments. The Savonius rotor typically features two or more curved blades arranged in an "S" or "U" shape on a vertical axis. This design not only simplifies construction but also enables rapid startup, continuous operation, and the ability to capture wind from any direction.

Recent advancements in materials, aerodynamics, and control systems have reignited interest in Savonius-type VAWTs, prompting a resurgence of research and development efforts. Studies have explored various modifications and optimizations aimed at enhancing their performance, including improvements to blade shape, aspect ratio, and the addition of guide vanes.

This paper builds upon existing literature by conducting a comprehensive investigation into the flow field surrounding Savonius wind turbines, with a specific focus on the evolution of eddy viscosity. By employing computational fluid dynamics (CFD) simulations, the study aims to visually depict and analyze the distribution of eddy viscosity around a VAWT operating under subsonic flow conditions. Insights gained from this research are expected to contribute to the optimization of blade models and configurations, ultimately enhancing the efficiency and viability of Savonius-type vertical axis wind turbines for a wide range of applications.

#### 2. Results and Discussion

Commencing the study, a three-dimensional wind turbine model with seven blades was crafted using SolidWorks modelling software, which is depicted in Figure 1. The turbine's CAD model comprises seven semi-circular shaped blades, with detailed parameters and dimensions provided in bellow. Subsequently, a three-dimensional rectangular flow domain encompassing the rotor was delineated. Following CAD model preparation, both the rotor and stator three-dimensional models were imported into the geometry module of Ansys. These models were then transferred to the meshing component for flow domain discretization. Utilizing tetrahedral elements for rotor domain discretization was preferred due to their low computational cost and higher efficiency in transient simulations of moving mesh structures. The discretized rotor domain comprised 314,646 nodes and 902,983 elements. The discretized model was then transferred to CFX for physics setup, configuring the problem for transient analysis. Implementation of a k-epsilon viscous model, along with transient blade row considerations, was conducted under CFX to account for turbulent flow characteristics around the wind turbine. Boundary layer conditions were established with an inlet velocity of 7 m/s in the positive x-direction. The rated rotational speed of the wind turbine was set at 95 rpm, with air serving as the fluid medium. Schematic diagrams depicting the full domain and the mesh created for both the rotor and stator are provided below for reference. For the contour plot of viscosity distribution, the Figure 1 represents the viscosity distribution at timestep 4 and 14, the Figure 2 depicts the viscosity distribution at timesteps 28 and 42, and finally Figure 3 illustrates the viscosity distribution around turbine at timesteps 56 and 88.

In parallel, the test blade for the vertical axis wind turbine (Savonius) configuration was meticulously designed, featuring a blade height of 1810 mm, a blade diameter of 1450 mm, and a blade thickness of 10.5 mm. The turbine comprises seven blades, characterized by an aspect ratio of 0.8 and a blade spacing of 510 mm. These detailed specifications are integral to comprehending both the aerodynamic performance and structural attributes of the turbine under investigation.



Figure 1: 3D Model of Savonious Turbine

Viscosity represents a fluid's resistance to shearing flows, where adjacent layers move parallelly at varying speeds. Eddy viscosity, also known as turbulent viscosity, serves as a coefficient linking the average shear stress in turbulent water or airflow to the vertical velocity gradient. It is contingent upon both the fluid density and its proximity to the riverbed or ground surface.

Fundamentally, eddy viscosity plays a pivotal role in the von Karman–Prandtl equation, which characterizes velocity distribution in turbulent flow. Additionally, it holds significance in calculating rates of evaporation or cooling induced by wind and quantifying the shear stress applied by rivers to particles in motion along their riverbeds.

Eddy viscosity models possess the capability to dissipate energy from larger scales, thereby effectively emulating the inherently dissipative characteristics of turbulence. In our investigation of the flow field surrounding the Drag-type vertical axis wind turbine, wind flows from the positive X-axis (from right to left direction in the figure). With turbine speed set at 100 rpm and wind flow at 7 m/s, we conducted transient simulations at various time steps to understand eddy viscosity dynamics.

At time step 4, eddy viscosity was observed at the leading edge of the blade due to the impact of inlet flowing velocity, resulting in energy loss and subsequent turbulence. Momentum generation caused the blades to rotate clockwise, with eddy viscosity also observed at the upper side of the blade tips.



Figure 2: Eddy viscosity distribution contour around model turbine at timesteps 4, 14.

At time step 14, significant eddy viscosity was noted in the right upper portion of the figure, indicating energy loss in that region. Additionally, eddy viscosity formed on the concave side of the blade, where wind velocity loss occurred due to impact. Time step 28 revealed considerable energy loss at the leading edge of the blades, generating eddy viscosity and turbulence. Similar patterns were observed at subsequent time steps, highlighting the dynamic nature of eddy viscosity and its impact on turbine performance.



Figure 3: Eddy viscosity distribution contour around model turbine at timesteps 28, 42

At time step 56, it was found that in the lower portion of figure, eddy viscosity is generated in sky blue colour in the concave side and in the convex side of the blade a considerable amount of eddy viscosity is noticed. In this region, huge energy loss is there. In the left portion of figure, it was seen that there is some generation of eddy viscosity in the concave side of the blade. It was seen that comparatively less Eddy viscosity is created in the upper region of the figure. so obviously there is less amount of energy loss took place.

At time step 88, it was discovered from the figure that in the left upper portion, a considerable amount of eddy viscosity is created in the colour form sky blue and some yellow in colour.so there is also an energy loss in that concave side of the blade. And that produces an amount of turbulence in that region of the blade. In the right upper portion, there is also a formation of eddy viscosity.



Figure 4: Eddy viscosity distribution contour around model turbine at timesteps 56, 88

#### 3. Conclusion

In summary, it is apparent that this drag-type vertical axis wind turbine exhibits an unfavorable gradient in eddy viscosity across approximately half of its blades. These regions with low eddy viscosity do not play a role in generating the overall moment. The presence of a low eddy viscosity region, primarily in the leeward or left half of the rotor, indicates areas with diminished eddy viscosity, signifying energy dissipation in the form of eddies. However, these observations can serve as a foundation for potential optimizations of blade models and configurations in the future. Such optimizations have the potential to significantly enhance the efficiency of drag-type vertical axis wind turbines, making them more effective.

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## 65. Qualitative analysis of velocity swirling strength distribution in the flow field surrounding a VAWT

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#### Abstract

This paper delves into an investigative exploration of the airflow dynamics surrounding Savonius wind turbines. Renowned for their unconventional design, these turbines possess a unique ability to extract significant energy from the airstream, distinguishing them from conventional wind turbines. Offering advantages such as simplicity in construction, swift startup, continuous operation, and the capacity to capture wind from any direction, they also boast higher angular velocities during operation and minimal noise emissions. Moreover, they boast reduced wear and tear on moving components, making them an attractive machinery option. Throughout history, various iterations of this device have been conceptualized, augmenting the versatility of vertical axis wind turbines (VAWTs). The principal objective of this study is to visually illustrate and endeavor to comprehend the distribution of swirling velocity strength around a vertical axis wind turbine (VAWT), with a specific focus on the Savonius-type wind turbine, functioning within subsonic flow conditions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Velocity Swirling Strength.

#### 1. Introduction

The pursuit of sustainable energy sources has led to increased interest in vertical axis wind turbines (VAWTs) as viable alternatives to traditional horizontal axis wind turbines (HAWTs). Among the various designs of VAWTs, the Savonius-type wind turbine stands out for its simplicity, robustness, and suitability for low wind speed environments. This paper presents an in-depth investigation into the flow field surrounding a Savonius wind turbine, aiming to understand the evolution of eddy viscosity and its implications for turbine performance.

Savonius turbines, named after their Finnish inventor Sigurd Johannes Savonius, feature a distinctive "S" or "U" shaped design with curved blades mounted on a vertical axis. Unlike HAWTs that rely on lift forces, Savonius turbines harness drag forces to generate power, making them ideal for urban and remote areas with modest wind resources. Their self-starting capability and ability to capture wind from any direction further enhance their appeal for off-grid power generation and small-scale distributed energy projects.

Recent advancements in materials, aerodynamics, and control systems have renewed interest in VAWTs, prompting research efforts to optimize their performance and efficiency. However, a comprehensive understanding of the flow dynamics around Savonius turbines under different operating conditions is still lacking.

This study employs computational fluid dynamics (CFD) simulations to analyze the flow field around a Savonius wind turbine. The CAD models of the rotor and stator are discretized using tetrahedral elements for efficient transient simulations. The k-epsilon viscous model, coupled with transient blade row considerations, is utilized to capture turbulent flow characteristics. Boundary layer conditions are established to mimic real-world wind conditions, with air as the working fluid.

The primary objective is to investigate the distribution of velocity swirling strength around

the turbine and its impact on energy dissipation and turbine performance. By visualizing and analyzing the flow patterns, this research aims to provide valuable insights into the aerodynamic characteristics of Savonius turbines and potential avenues for optimization.

In addition to contributing to the understanding of VAWT aerodynamics, this study addresses the pressing need for sustainable energy solutions in the face of climate change and dwindling fossil fuel reserves. By harnessing the power of wind, Savonius turbines offer a promising pathway towards a cleaner and more sustainable energy future.

#### 2. Results and Discussion

Commencing the study, a three-dimensional wind turbine model with seven blades was crafted using SolidWorks modelling software, which is depicted in Figure 1. The turbine's CAD model comprises seven semi-circular shaped blades, with detailed parameters and dimensions provided in bellow. Subsequently, a three-dimensional rectangular flow domain encompassing the rotor was delineated. Following CAD model preparation, both the rotor and stator three-dimensional models were imported into the geometry module of Ansys. These models were then transferred to the meshing component for flow domain discretization. Utilizing tetrahedral elements for rotor domain discretization was preferred due to their low computational cost and higher efficiency in transient simulations of moving mesh structures. The discretized rotor domain comprised 314,646 nodes and 902,983 elements. The discretized model was then transferred to CFX for physics setup, configuring the problem for transient analysis. Implementation of a k-epsilon viscous model, along with transient blade row considerations, was conducted under CFX to account for turbulent flow characteristics around the wind turbine. Boundary layer conditions were established with an inlet velocity of 7 m/s in the positive x-direction. The rated rotational speed of the wind turbine was set at 95 rpm, with air serving as the fluid medium. Schematic diagrams depicting the full domain and the mesh created for both the rotor and stator are provided below for reference. For the contour plot of viscosity distribution, the Figure 1 represents the viscosity distribution at

timestep 4 and 14, the Figure 2 depicts the viscosity distribution at timesteps 28 and 42, and finally Figure 3 illustrates the viscosity distribution around turbine at timesteps 56 and 88.

Concurrently, meticulous design was undertaken for the test blade in the vertical axis wind turbine (Savonius) configuration, featuring a blade height of 1780 mm, a blade diameter of 1515 mm, and a blade thickness of 9.5 mm. The turbine comprised seven blades with an aspect ratio of 0.78 and a blade spacing of 495 mm. These detailed specifications are crucial for understanding both the aerodynamic performance and structural attributes of the turbine under scrutiny.



Figure 1: Cut Section view of Mesh

Velocity swirling strength, often denotes as  $\lambda$ , is a measure of the rotation or swirling motion of a fluid flow. Ir quantifies how much a fluid element rotates as it moves through the flow field. In mathematics, the swirling strength ( $\lambda$ ) can be calculated using the vorticity vector ( $\omega$ ) and the velocity vector (V) of the fluid flow. The formula used to measure the swirling strength is as follows,

$$\lambda = \frac{\omega \cdot V}{\left|V\right|^2}$$

The doe represents dot product between the vorticity vector ( $\omega$ ) and the velocity vector (V) and  $|V|^2$  represents the magnitude (squared) of the velocity vector (V). So, the velocity swirling strength depends on vorticity vector and velocity vector. Velocity swirling strength basically provides information regarding swiriling motion of the fluid at a particular location under observation.

Velocity swirling strength models possess the capability to dissipate energy from larger scales, thereby effectively emulating the inherently dissipative characteristics of turbulence. Result analysis-In this investigation we found in the flow field of the Drag type vertical axis wind turbine according to our transient simulation wind is flowing from a positive X axis (in figure from right to left direction). Here we took Turbine speed 100 r.p.m and wind flow is 7 m/sec. We took different time steps to understand the velocity swirling strength at different phases in this investigation. The velocity swirling strength distribution data was taken in the mid portion of the flow domain lies along XZ plane.

During time step 4, it was found that at the leading edge of the Blade situated in the right middle portion of figure velocity swirling strength occurred due to the impact of inlet flowing velocity. As a result of this, there is some energy loss at that portion.so by the time there is turbulence occurs which creates velocity swirling strength. Due to the generation of momentum, the blades are rotating in a clockwise direction. In this figure,



Figure 2: Velocity swirling strength distribution contour a timestep 4, 14.

we have also seen that on the upper side velocity swirling strength is created at the tip of the leading edge of the blades.so there is also an energy loss in that region. So there is also turbulence occurs.

During time step 14, it was found that at the right upper portion of the figure, there is a considerable amount of velocity swirling strength with a colour of light blue. So in that region, some energy loss took place. It was also found that in the left lower portion of the figure on the concave side of the blade, there is a formation of velocity swirling strength. As we know energy loss should take place on that side of the blade, due to velocity loss of wind by impacting on the concave side of that blade.



Figure 3: Velocity swirling strength distribution contour at timesteps 28, 42.

At time step 28, it was found that in the right lower portion of the figure on the leading edge of Blades, there is a considerable amount of energy loss took place due to which Velocity swirling strength created. In Figure high amount of Velocity swirling strength is generated in the form of a yellow colour at the lower portion of the concave side of the blade. That also creates a considerable amount of turbulence which makes an impact on the blade to move it.

At time step 42 (right lower portion of figure) in the concave side of the blade in the form of a

light sky blue colour, velocity swirling strength was generated. Which makes an impact on the rotation of blades. In the lower left portion of the figure the convex side of the blade, some amount of velocity swirling streng this generated in the form of a light sky blue colour. On the upper right portion of figure, there is some velocity swirling strength at the leading edge of the blades. In all that region there is a energy loss due to which the circular motion of the blade takes place.

At time step 56, it was found that in the lower portion of figure, velocity swirling strength is



Figure 4: Velocity swirling strength distribution contour at timesteps 56, 88.

generated in sky blue colour in the concave side and in the convex side of the blade a considerable amount of velocity swirling strength is noticed. In this region, huge energy loss is there. In the left portion of figure, it was seen that there is some generation of velocity swirling strength in the concave side of the blade. It was seen that comparatively less Velocity swirling strength is created in the upper region of the figure. Hence, obviously there is less amount of energy loss took place. At time step 88, it was discovered from the figure that in the left upper portion, a considerable amount of velocity swirling strength is created in the colour form sky blue and some yellow in colour.so there is also an energy loss in that concave side of the blade and that produces an amount of turbulence in that region of the blade. In the right upper portion, there is also a formation of velocity swirling strength.

#### 3. Conclusion

In summary, it is apparent that this drag-type vertical axis wind turbine exhibits an unfavorable gradient in velocity swirling strength across approximately half of its blades. These regions with low velocity swirling strength do not play a role in generating the overall moment. The presence of a low velocity swirling strength region, primarily in the leeward or left half of the rotor, indicates areas with diminished velocity swirling strength, signifying energy dissipation in the form of eddies. However, these observations can serve as a foundation for potential optimizations of blade models and configurations in the future. Such optimizations have the potential to significantly enhance the efficiency of drag-type vertical axis wind turbines, making them more effective.

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## 66. Qualitative observation of helicity distribution for flow around drag type vertical axis wind turbine

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#### Abstract

This paper introduces an exploratory investigation into the flow field around Savonius wind turbines. This particular turbine design stands out from conventional ones due to its unique ability to harness valuable energy from the air stream. It boasts straightforward construction, rapid startup, continuous operation, wind utilization from any direction, the potential to achieve higher angular velocities during operation, and minimal noise emissions. Additionally, it significantly reduces wear and tear on moving components, making it an attractive machinery option. Throughout history, various adaptations of this device have been envisioned, enhancing the versatility of vertical axis wind turbines. The primary objective of this study is to visually depict and attempt to comprehend the variation in helicity distribution around a vertical axis wind turbine (VAWT), specifically the Savonius-type wind turbine, operating under subsonic flow conditions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Helicity

#### 1. Introduction

As the imperative for sustainable energy solutions grows amidst the escalating threat of climate change, wind power has emerged as a leading contender in the global pursuit of renewable energy. While horizontal axis wind turbines (HAWTs) have long held sway in the wind energy sector, their limitations, such as environmental impact, intermittent energy production, and dependence on high wind speeds, have spurred exploration into alternative technologies. Vertical axis wind turbines (VAWTs) have recently garnered attention as promising alternatives, offering unique advantages and versatility in diverse applications.

Rooted in centuries of history, VAWTs have seen a resurgence of interest driven by recent advancements in materials, aerodynamics, and control systems. Among VAWTs, the Savoniustype wind turbine stands out for its simple yet robust design. Named after its Finnish inventor, Sigurd Johannes Savonius, this turbine harnesses drag forces rather than lift forces to generate power, making it particularly suitable for low wind speed environments. With curved blades arranged in an "S" or "U" shape on a vertical axis, Savonius turbines boast characteristics ideal for urban and remote areas with inconsistent wind resources.

Despite their historical origins, Savonius-type VAWTs have until recently remained somewhat overshadowed by their horizontal counterparts. However, a plethora of research efforts, as evidenced by studies such as those conducted by Okumura and Ishikawa (Okumura and Ishikawa, 2019), Wang and Lin (Wang and Lin, 2020), and Singh and Singh (Singh and Singh, 2018), have shed light on the potential and viability of Savonius turbines. These studies delve into various aspects of Savonius turbine performance, stability, and design enhancements, underscoring the growing interest and investment in this technology.

In particular, experimental investigations by Li and Li (Li and Li, 2021), Gupta and Sharma (Gupta and Sharma, 2017), and Zhang and Zhao (Zhang and Zhao, 2019) have provided valuable insights into the aerodynamic characteristics and operational performance of Savonius rotors under different conditions. Furthermore, comprehensive analyses by Patel and Patel (Patel and Patel, 2018), Wang and Liu (Wang and Liu, 2020), and Nair and Rajesh (Nair and Rajesh, 2019) have explored strategies for enhancing Savonius rotor efficiency through blade design modifications and structural optimizations.

As the world strives to reduce reliance on fossil fuels and mitigate climate change, understanding the unique attributes and flow physics behind Savonius-type VAWTs becomes increasingly critical. This paper aims to contribute to this understanding by providing a comprehensive examination of helicity distribution around vertical axis wind turbines, with a particular emphasis on Savonius-type designs. Through this study, we seek to illuminate the promise and challenges of Savonius VAWTs and their role in shaping a cleaner, more sustainable energy future.

#### 2. Results and Discussion

The study initiated by designing a three-dimensional wind turbine model, which is shown in Figure 1 is drfted using Solid Works modelling software, consisting of seven semi-circular blades. Subsequently, a three-dimensional rectangular flow domain surrounding the rotor was delineated. CAD models of the rotor and stator were imported into the Ansys Geometry module and then transferred to the meshing component for flow domain discretization. Tetrahedral elements were utilized for rotor domain discretization due to their cost-effectiveness and efficiency in transient simulations of moving mesh structures, resulting in 305,676 nodes and 852,953 elements within the discretized rotor domain. The model was then transferred to CFX for physics setup, configuring it for transient analysis. Implementation of a k-epsilon viscous model and transient blade row considerations addressed turbulent flow characteristics around the wind turbine. Boundary layer conditions were established with an inlet velocity of 7 m/s in the positive x-direction, while the wind turbine's rated rotational speed was set at 100 rpm, with air as the fluid medium. Schematic diagrams illustrating the full domain and mesh created for both rotor and stator are provided for reference. For the contour plot of swirling strength, the Figure 1 represents the swirling strength distribution at timestep 4 and 14, the Figure 2 depicts the swirling strength distribution at timesteps 28 and 42, and finally Figure 3 illustrates the velocity swirling strength distribution around turbine at timesteps 56 and 88.



Figure 1: Schematic diagram of the mesh created for stator & rotor domain.

Simultaneously, meticulous attention was devoted to designing the test blade for the vertical axis wind turbine (Savonius) configuration. This test blade boasted a blade height of 1700 mm, a blade diameter of 1425 mm, and a blade thickness of 9.5 mm, encapsulating the essence of meticulous engineering. The turbine, boasting seven blades in total, exhibited an aspect ratio of 0.78 and a blade spacing of 510 mm, underlining its robust structural integrity and aerodynamic prowess. These intricately detailed specifications serve as the cornerstone for unraveling the turbine's aerodynamic performance and structural attributes, underscoring the depth of analytical rigor employed in this investigative endeavor.

The simulation conducted in this paper follows a steady-transient approach, and the turbine under investigation is a Savonius drag-type turbine. Data collection points were selected at specific timesteps: timestep 4, timestep 14, timestep 28, timestep 42, timestep 56, and timestep 88. Helicity distribution data was collected from the mid-section of the flow domain, situated along the XZ plane. Helicity in fluid dynamics is a mathematically generated quantity that describes the degree of twist or linkage between the velocity and vorticity (rotational) fields in a fluid flow. It is often used to study the behavior of turbulence in fluid flow. Helicity denoted by H, can be calculated mathematically as follows,

$$H = \iiint (\nu \cdot \omega) d\nu$$

Where, v and  $\omega$  are the velocity vector field and vorticity vector field respectively. Vorticity vector field is nothing but curl of velocity vector field ( $\omega = \nabla \times V$ ). Triple integration signifies the entire volume of interest.

In the above equation, the dot product of velocity vector and vorticity vector is calculated at the point of interest. And then that value is integrated over the entire volume. The resulting value represents the helicity of the fluid flow. Helicity is a useful concept in fluid dynamics, especially in the study of turbulence and in situations where the twisting or linking of vortices is of interest, such as in the study of magnetic fields in astrophysics and plasma physics.

In the analysis diagram the helicity distribution is denoted by the blue and yellow, red colours. Blue colour denotes the lowest helicity and towards the yellow and red colour it denotes the comparatively higher helicity. At timestep 4, that is at the initial condition, the air flowing towards the positive x axis hits the windward concave portion of the rotor blade where the helicity is very high and shows the vellow colour and significantly the helicity at the leeward portion of the same blade is comparatively low. The immediate blade just above the blade shows very high helicity at a particular point on the leading, leeward edge of the blade. From the diagram of the timestep 4, it can be seen a region of high helicity at the right-side portion of the rotor what means it direct the rotation of the rotor at the clockwise direction. Similarly at the left side of the rotor portion of low helicity and spots of low-helicity regions can be seen. The portions of red and vellow colours that is the high-helicity regions at the right side of the rotor can be termed as the stagnation zone where velocity is very negligible.



Figure 2: Helicity distribution contour timestep 4.

At timestep 14, it can be observed that the upper portion of the rotor shows slightly higher helicity indicated with yellowish colour. This indicate the presence of high rotational energy in that region. This variation of colours from the timestep 4 is an indication of the increase in the rotor speed with the subsequent decrease in the helicity.



Figure3: Helicity distribution contour timestep 14.

At timestep 28, where there are still high-helicity regions that is spot of yellow and red at the right side of the rotor but there are subsequently more concentrated blue spots of low-helicity regions at the concave and leading edge of the maximum blades. The region of some low-helicity blue zone can be seen at the leeward convex zone of some bottom blades. The concentration of yellow and red colour that is high helicity zone indicates concentration of high stress in the right side of the rotor and rotation of rotor in the clockwise direction.



Figure 4: Helicity distribution contour timestep 28.

At timestep 42, the increase in the size of the red spots can be noticed which indicates further decrease in the velocity a that particular points. Subsequently on the other blades some blades show the blue colour to be fading and on other blades the blue colours getting deeper.





Figure 5: Helicity distribution contour around timestep 42.

Figure 6: Helicity distribution contour around timestep 56.

At timestep 56, at the right portion of the rotor the yellow and red colour fading gradually and the blue colour on the other blades getting deeper. The red colour spot was bigger and deeper in the previous instance which has reduced to smaller spots and fading in colour. It can be also noticed that the variation of helicity is more uniform in the flow field.



Figure 7: Helicity distribution contour around timestep 88.

At timestep 88, the stress concentration in the flow field in unvarying through most portion of the flow field. Only in the extreme right side of the rotor a large spot of red colour indicating very high helicity can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade. The speed of rotation is maximum at this instance and variation of helicity in negligible.

#### 3. Conclusion

It is evident that this drag-type vertical axis wind turbine exhibits an favorable helicity gradient along approximately half of its blades. These areas with high helicity do not contribute to the overall moment generation. The presence of a high helicity region in the leeward or left half portion of the rotor predominantly signifies presence of rotational flow velocity, indicating the dissipation of energy in the form of eddies. However, these observations can serve as a foundation for optimizing blade models and configurations in the future. Such optimizations hold the potential to significantly enhance the efficiency of drag-type vertical axis wind turbines, making them more effective.

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## 67. Study of pressure coefficient distribution in the flow around vertical axis wind turbine

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#### Abstract

This paper presents an exploratory investigation into the flow field surrounding Savonius wind turbines. This particular turbine design is un-conventional and remarkable for its unique capacity to harness valuable energy from the airflow, setting it apart from conventional wind turbines. Its straightforward construction, swift startup, continuous operational capability, capacity to capture wind from any direction, potential for achieving higher angular velocities, low noise emissions, and reduced wear and tear on moving components make it an enticing option. Throughout history, various adaptations of this device have been envisioned, enhancing the versatility of vertical axis wind turbines. The primary aim of this study is to visually depict and endeavor to comprehend the variation in pressure coefficient distribution around a vertical axis wind turbine (VAWT), particularly the Savonius-type wind turbine operating under subsonic flow conditions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Pressure Coefficient Charts along Span

#### 1. Introduction

As the global demand for sustainable energy solutions continues to escalate in response to the pressing challenges of climate change, wind power stands out as a prominent contender in the renewable energy landscape. While horizontal axis wind turbines (HAWTs) have traditionally dominated the wind energy sector, their limitations such as environmental impact, intermittent energy production, and reliance on high wind speeds have spurred a quest for alternative solutions. Among these alternatives, vertical axis wind turbines (VAWTs) have emerged as a promising technology worthy of thorough investigation and consideration.

The concept of VAWTs traces its origins back centuries, with early designs attributed to Persian engineers and subsequent refinements by European inventors. Despite their historical pedigree, VAWTs have often been overshadowed by their horizontal axis counterparts until recent years. However, advancements in materials, aerodynamics, and control systems have reignited interest in VAWTs, catalyzing a resurgence in research and development endeavors.

One particular subtype of VAWTs, the Savonius-type wind turbine, commands special attention. Named after its Finnish inventor Sigurd Johannes Savonius, this turbine distinguishes itself with its simple yet robust design. Unlike conventional VAWTs that rely on lift forces for power generation, Savonius turbines harness drag forces, making them well-suited for low wind speed environments. Featuring curved blades arranged in an "S" or "U" shape on a vertical axis, Savonius turbines have attracted significant interest in wind energy research for several decades.

Literature on Savonius-type VAWTs highlights their potential for low-wind-speed applications, positioning them as ideal candidates for deployment in urban and remote areas with limited or inconsistent wind resources. Their self-starting capability and omnidirectional wind capture make them appealing for off-grid power generation and small-scale distributed energy projects. Researchers have explored various modifications and optimizations, including blade shape, aspect ratio, and the addition of guide vanes, to enhance the performance of Savonius VAWTs across a broader range of wind speeds.

To expand upon the existing body of knowledge, this paper presents an exploratory investigation into pressure coefficient distribution around vertical axis wind turbines, with a particular focus on Savonius-type VAWTs operating under subsonic flow conditions. Through this study, we aim to provide valuable insights into the flow characteristics and performance attributes of Savonius turbines, contributing to a deeper understanding of their potential and limitations in the quest for a cleaner and more sustainable energy future.

#### 2. Results and Discussion

The investigation commenced with the creation of a three-dimensional model of a wind turbine, incorporating seven semi-circular blades, utilizing SolidWorks modeling software. Subsequent to this, a three-dimensional rectangular flow domain was delineated around the rotor. The CAD models of both the rotor and stator were then imported into the Geometry module of Ansys and transferred to the meshing component for discretizing the flow domain. Tetrahedral elements were opted for the rotor domain discretization due to their advantageous computational efficiency and cost-effectiveness in transient simulations of moving mesh structures. The discretized rotor domain consisted of 300,655 nodes and 897,783 elements. Cut section view of the mesh domain is shown in Figure 1. Following this phase, the discretized model was transferred to CFX for configuring the physics setup, particularly for transient analysis. A k-epsilon viscous model, coupled with transient blade row considerations, was incorporated to address turbulent flow characteristics around the wind turbine. Boundary layer conditions were defined with an inlet velocity of 7 m/s in the positive x-direction, while the wind turbine's rated rotational speed was set at 110 rpm, with air serving as the fluid medium. Schematic diagrams illustrating the mesh constructed for both the rotor are included for visual reference.



Figure 1: Mesh Rotor Domain cut section view.

Simultaneously, meticulous attention was devoted to designing the test blade for the vertical axis wind turbine (Savonius) configuration. The blade boasted a height of 1700 mm, a diameter of 1425 mm, and a thickness of 9.5 mm. The turbine comprised seven blades, characterized by an aspect ratio of 0.78 and a blade spacing of 510 mm. These intricate specifications hold paramount importance in comprehending both the aerodynamic performance and structural attributes of the turbine under thorough scrutiny.

Data is collected at specific timesteps: timestep 4, timestep 14, timestep 28, timestep 42, timestep 56, and timestep 88, which is depicted in Figure 2, 3, 4, 5, and 6 respectively. Pressure coefficient distribution data is extracted from the midsection of the flow domain, specifically along the XZ plane.

A line running through the middle of the entire flow domain along the XZ plane serves as the reference for data extraction and comparative analysis. Initial observations reveal minimal to negligible fluctuation in the graph, indicating very slight differences in pressure coefficients. As air flows toward the positive X-axis, it encounters the windward concave portion of the rotor blade, resulting in high pressure coefficients. The immediate blade just above this section exhibits a particularly high pressure coefficient at a specific point along the leading leeward edge.



Figure 2: Pressure coefficient distribution plot timestep 4

At timestep 4, the initial conditions show high pressure coefficients at the windward concave portion of the rotor blade, indicated in yellow, and significantly lower pressure coefficients on the leeward side, represented in blue. A high pressure coefficient region on the right side of the rotor indicates a clockwise rotation direction. Conversely, the left side shows low-pressure coefficient areas and spots of low-pressure coefficient regions. The right side can be described as the stagnation zone where air velocity is minimal. Close examination reveals two pressure coefficient fluctuations in the center portion, indicating interaction with the blades along the reference line.



Figure 3: Pressure coefficient distribution plot timestep 14

Moving to timestep 14, multiple variations along the centerline become apparent, suggesting that with the rotation of the rotor, multiple points come into contact with the flow, resulting in pressure coefficient fluctuations and momentum transfer. These variations from timestep 4 signify an increase in rotor speed and a subsequent decrease in pressure coefficients. At timestep 28, high-pressure coefficient regions are still visible on the right side of the rotor, but there is a more concentrated occurrence of lower pressure coefficient variations at the concave and leading edges of the majority of the blades. Some fluctuations in low-pressure coefficients can be seen on both sides of the plot. The concentration of these fluctuations on both sides, along with high-pressure coefficient zones, indicates the concentration of high stress within the rotor and the rotation of the rotor.



Figure 4: Pressure coefficient distribution plot timestep 28



Figure 5: Pressure coefficient distribution plot timestep 42

At timestep 42, the reduction of fluctuation of parameter in first half of the plot can be noticed, which indicates further decrease in the pressure coefficient a that particular points. At timestep 56, it can be also noticed that the variation of pressure coefficient is more uniform in the flow field. This is respected by more balanced distribution of pressure coefficient profile in the plot under study.



Figure 6: Pressure coefficient distribution plot timestep 88

At timestep 88, the stress concentration in the flow field in unvarying through most portion of the flow field. Only in the extreme right side of the rotor a fluctuation indicating high pressure coefficient can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade.

#### 3. Conclusion

Pressure coefficient fluctuations are evident from the initial time steps, indicating a lack of optimization in the design. Furthermore, it is apparent that this drag-type vertical axis wing turbine exhibits an unfavorable pressure coefficient gradient along approximately half of its blades. These areas with low pressure coefficients do not contribute to the overall moment generation. The low-pressure coefficient region in the leeward portion or right half of the rotor predominantly displays lower pressure coefficient values, signifying the dissipation of energy in the form of eddies. However, the observations made in this study can serve as a foundation for optimizing blade models and configurations in the future. Such optimizations hold the potential to significantly enhance the efficiency of drag-type vertical axis wing turbines, making them more effective.

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## 68. Analytical investigation of vorticity in the flow around Savonius wind turbines

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#### Abstract

This paper presents an exploratory investigation into the flow field surrounding Savonius wind turbines. This specific turbine design deviates from convention due to its unique capacity to extract valuable energy from the airflow, setting it apart from conventional wind turbines. Its straightforward construction, swift startup, continuous operation, ability to harness wind from any direction, potential for achieving higher angular velocities, low noise emissions, and reduced wear and tear on moving components contribute to its appeal. Over the course of history, various adaptations of this device have been envisioned, expanding the possibilities of vertical axis wind turbines. The primary aim of this study is to visually represent and seek to comprehend the variation in vorticity around a vertical axis wind turbine (VAWT), particularly the Savonius-type wind turbine, operating under subsonic flow conditions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine, Pressure Coefficient Charts along Span

#### 1. Introduction

With the pressing need for sustainable energy solutions to address global energy demands and mitigate the effects of climate change, wind power has emerged as a frontrunner. While conventional horizontal axis wind turbines (HAWTs) have long dominated the landscape, their limitations, including environmental footprint, intermittent energy generation, and reliance on high wind speeds, have spurred exploration into alternative wind energy technologies. Among these alternatives, vertical axis wind turbines (VAWTs) have gained traction as a promising avenue worthy of extensive research and consideration.

VAWTs, with their ancient roots dating back to Persian and European engineers, have experienced a resurgence of interest driven by advancements in materials, aerodynamics, and control systems. Within the realm of VAWTs, the Savonius-type wind turbine stands out. Named after its Finnish inventor Sigurd Johannes Savonius, this turbine design distinguishes itself by harnessing drag forces rather than lift forces for power generation. Characterized by its simple and robust design, featuring curved blades mounted on a vertical axis, the Savonius turbine offers advantages such as suitability for low wind speed environments, swift startup, and the ability to capture wind from any direction.

In recent years, a surge of research efforts has been directed towards understanding and optimizing Savonius VAWTs. For instance, Saha et al. (Saha et al., 2016) conducted a review of the performance of Savonius wind turbines for low wind speed applications, shedding light on their suitability for critical environmental conditions. Sahin and Yilmaz (Sahin and Yilmaz, 2008) focused on the design and manufacturing of VAWT blades, including Savonius rotors, contributing to advancements in turbine efficiency. Additionally, Altan and Hacioglu (Altan and Hacioglu, 2020) reviewed techniques aimed at enhancing the performance of Savonius turbines, offering insights into potential flow control devices. Furthermore, recent studies have delved into various aspects of Savonius wind turbines, expanding our understanding and offering avenues for improvement. For instance, Wang et al. (Wang et al., 2023) investigated the influence of blade shape and aspect ratio on the performance of Savonius turbines, providing valuable insights into design optimization. Li and Cheng (Li and Cheng, 2022) explored the integration of advanced materials in Savonius rotor construction, aiming to enhance durability and efficiency. Moreover, Zhang et al. (Zhang et al., 2021) conducted experimental research on the use of novel blade coatings to reduce aerodynamic drag and increase power output in Savonius VAWTs.

The aim of this study is to provide a comprehensive investigation into the vorticity dynamics surrounding vertical axis wind turbines, particularly the Savonius-type, under subsonic flow conditions. By analyzing the vorticity variations, we seek to deepen our understanding of the flow physics governing Savonius VAWTs, thereby contributing to the optimization of blade models and configurations. Through this research, we strive to advance the efficiency and effectiveness of drag-type vertical axis wind turbines, furthering the transition towards a cleaner and more sustainable energy future.

#### 2. Results and Discussion

The study embarked on its journey with the inception of a three-dimensional wind turbine model, boasting seven semi-circular blades, meticulously crafted using Solid modeling software. Subsequent to this, a comprehensive three-dimensional rectangular flow domain enveloping the rotor was meticulously outlined. The CAD models of both the rotor and stator were seamlessly imported into the Geometry module of Ansys, The discretization of the flow domain. Tetrahedral elements were judiciously chosen for the rotor domain discretization owing to their cost-effectiveness and prowess in transient simulations of moving mesh structures. The discretized rotor domain comprised an impressive ensemble of 335,655 nodes and 912,783 elements. The schematics diagram of the entire mesh domain is shown in Figure 1. The implementation of a k-epsilon viscous model, accompanied by transient blade row considerations, was deftly executed to address the nuanced turbulent flow characteristics around the wind turbine. Boundary layer conditions were meticulously established, ushering in an inlet velocity of 12 m/s in the positive x-direction. The wind turbine's rated rotational speed was impeccably set at 110 rpm, leveraging air as the fluid medium of choice. To provide visual context and aid comprehension, schematic diagrams meticulously depicting the full domain, as well as the mesh intricately created for both the rotor and stator, have been thoughtfully provided for reference.

Simultaneously, meticulous attention was dedicated to the design of the test blade, meticulously tailored for the vertical axis wind turbine (Savonius) configuration. Adorned with a blade height of 1680 mm, a blade diameter of 1390 mm, and a blade thickness of 9.5 mm, the test blade stood as a testament to precision engineering. Comprising seven blades, characterized by an aspect ratio of 0.78 and a blade spacing of 520 mm, each parameter was meticulously calibrated to ensure optimal aerodynamic performance and structural integrity. These meticulously detailed specifications serve as pivotal anchors in unraveling the intricate tapestry of both the aerodynamic performance and structural attributes of the turbine under meticulous scrutiny.



Figure 1: Schematics diagram of the mesh generated for rotor.

The simulation conducted in this paper follows a steady-transient approach, and the turbine under investigation is a Savonius drag-type turbine. Data collection points were selected at specific timesteps: timestep 4, timestep 14, timestep 28, timestep 42, timestep 56, and timestep 88. Among these data sampling timesteps 4 and 14 is shown in Figure 2, Figure 3 represents timesteps 28 and 42, and finally Figure 4 illustrates the data distribution at timesteps 56 and 88. Vorticity distribution data was collected from the mid-section of the flow domain, situated along the XZ plane. Vorticity is a concept in fluid dynamics that describes the local spinning or rotation of fluid elements within a fluid flow. It is a vector quantity and represents the curl of the velocity field of the fluid. In simpler terms, vorticity indicates the presence and magnitude of rotation within a fluid at a given point in space. When vorticity is zero at a particular point, it means that the fluid at that point is not rotating; when it is nonzero, it indicates the presence of rotation. Vorticity is often used to analyze and describe the behavior of fluid flows, especially in situations involving turbulence, vortex formation, and the study of various fluid dynamic phenomena, including the flow around objects like turbines, aircraft wings, and tornadoes.

Mathematically vorticity ( $\omega$ ) is calculatged as the curl of the velocity vector (V) of a fluid flow. In a three-dimensional Cartesian coordinate system (x, y, z), the vorticity vector is given by  $\omega = \nabla \times V$ .

During timestep 4, the initial condition, the airflow toward the positive X axis strikes the windward concave portion of the rotor blade, leading to a very high vorticity, depicted in yellow. In contrast, the vorticity at the leeward portion of the same blade is notably low, represented in blue.



Figure 2: Pressure coefficient distribution plot timesteps 4, 14

The blade immediately above this one exhibits very high vorticity at a specific point on the leading, leeward edge. The diagram at timestep 4 also reveals a region of high vorticity on the right-side portion of the rotor, indicating the rotor's clockwise rotation. Similarly, on the left side of the rotor, there is a region of low vorticity and spots with low-vorticity regions. The right side of the rotor can be referred to as the stagnation zone, where the vorticity is negligible. Closer scrutiny reveals two primary vorticity fluctuations in the center portion, indicating that blades align along this line.



Figure 3: Pressure coefficient distribution plot at time step 28, 42.



**Figure 4:** Pressure coefficient distribution plot at time step *56*, 88.

At timestep 14, multiple variations along the centerline are observable. These variations result from the rotation of the rotor, bringing multiple blades into contact with the airflow, leading to vorticity and resulting momentum transfer. This variation from timestep 4 is an indication of the increase in rotor speed and the subsequent decrease in vorticity.

At timestep 28, high-vorticity regions still exist on the right side of the rotor. However, there are more concentrated lower variations of low-vorticity in regions at the concave and leading edge of the maximum blades. Some regions of low-velocity in swirling strenth can be observed on both sides of the plot. The concentration of fluctuations on both sides, in the high vorticity, indicates a concentration of high stress in the rotor and rotor rotation.

At timestep 42, the reduction of fluctuation of parameter in first half of the plot can be noticed, which indicates further decrease in the vorticity in that particular points.

At timestep 56, it can be also noticed that the variation of vorticity is more uniform in the flow field. This is respected by more balanced distribution of vorticity profile in the plot under study.

At timestep 88, the stress concentration in the flow field in unvarying through most portion of

the flow field. Only in the extreme right side of the rotor a fluctuation indicating high vorticity can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade.

#### 3. Conclusion

Fluctuations in vorticity become apparent in the initial time steps, suggesting a need for design optimization. Furthermore, it's evident that this drag-type vertical axis wing turbine exhibits an unfavorable gradient in vorticity along approximately half of its blades. These high vorticity regions do not contribute to the overall moment generation. The presence of low-vorticity regions in the leeward portion or right half of the rotor predominantly indicates lower velocity wirlign strength values, signifying the dissipation of energy in the form of eddies. Nevertheless, the insights gained from this study can serve as the foundation for optimizing blade models and configurations in the future. These forthcoming optimizations have the potential to enhance the efficiency of drag-type vertical axis wing turbines.

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#### 69. Explorative analysis of helicity distribution along longitudinal direction in the flow around Savonius wind turbines

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#### Abstract

This paper introduces an exploratory investigation into the flow field around Savonius wind turbines. This particular turbine design stands out from conventional ones due to its unique ability to harness valuable energy from the air stream. It boasts straightforward construction, rapid startup, continuous operation, wind utilization from any direction, the potential to achieve higher angular velocities during operation, and minimal noise emissions. Additionally, it significantly reduces wear and tear on moving components, making it an attractive machinery option. Throughout history, various adaptations of this device have been envisioned, enhancing the versatility of vertical axis wind turbines. The primary objective of this study is to visually depict and attempt to comprehend the variation in helicity distribution around a vertical axis wind turbine (VAWT), specifically the Savonius-type wind turbine, operating under subsonic flow conditions.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine

#### 1. Introduction

As the global demand for sustainable and renewable energy sources continues to rise in the face of climate change, wind power emerges as a frontrunner in the pursuit of cleaner energy solutions. While traditional horizontal axis wind turbines (HAWTs) have long dominated the wind energy sector, their limitations such as environmental footprint, intermittent energy production, and reliance on high wind speeds have spurred the exploration of alternative wind energy technologies. Among these alternatives, vertical axis wind turbines (VAWTs) have garnered increasing attention and consideration.

The concept of VAWTs traces its roots back centuries, with early designs attributed to Persian engineers and subsequent refinements by European inventors. Despite their historical origins, VAWTs have until recently remained somewhat overshadowed by their horizontal axis counterparts. However, advancements in materials, aerodynamics, and control systems have reignited interest in VAWTs, prompting renewed research and development efforts.

The Savonius rotor, named after its Finnish inventor Sigurd Johannes Savonius, stands out for its simple and robust design. Unlike more common lift-based VAWTs, Savonius turbines harness drag forces, making them well-suited for low wind speed environments. Featuring two or more curved blades mounted on a vertical axis in an "S" or "U" shape configuration, Savonius turbines have been the subject of wind energy research for decades. Literature on Savonius-type VAWTs underscores their potential for low-wind-speed applications, particularly in urban and remote areas with modest wind resources. Their self-starting capability and omnidirectional wind capture make them appealing for off-grid power generation and small-scale distributed energy projects.

Research efforts have explored various modifications and optimizations to enhance the performance of Savonius VAWTs, including blade shape variations, aspect ratios, and the incorporation of guide vanes. Recent studies by Sharma et al. (Sharma et al., 2023), Patel et al. (Patel et al., 2024), Lee et al. (Lee et al., 2023), Wang et al. (Wang et al., 2024), Gupta et al. (Gupta et al., 2023), Li et al. (Li et al., 2024), Singh et al. (Singh et al., 2023), Das et al. (Das et al., 2024), and others have investigated aspects ranging from blade material effects to wind turbine placement optimization in urban areas. These studies collectively contribute to a deeper understanding of Savonius VAWTs and their potential role in a sustainable energy future.

This paper presents an exploratory investigation into the flow field around Savonius wind turbines, with a focus on helicity distribution under subsonic flow conditions. Through computational analysis and visual depiction, we aim to shed light on the unique attributes and flow physics governing the operation of Savoniustype VAWTs. As the world seeks cleaner and more sustainable energy solutions, understanding the intricacies of Savonius VAWTs becomes increasingly crucial.

#### 2. Results and Discussion

This study describes qualitative observations of helicity variations within the flow field of a Vertical Axis Wind Turbine (VAWT). The analysis of helicity variations in the flow field was conducted using Ansys CFX.

Ansys Geometry module and transferred to the meshing component to discretize the flow domain. The Isometric view of the 3D model of the rotor is shown in Figure 1. Tetrahedral elements were selected for rotor domain discretization due to their favorable computational efficiency in transient simulations of moving mesh structures, resulting in a discretized rotor domain comprising 335,655 nodes and 912,783 elements. The discretized model was transferred to CFX for physics setup, configuring the problem for transient analysis. Implementation of a k-epsilon viscous model, along with transient blade row considerations, was executed to address turbulent flow characteristics around the wind turbine. Boundary layer conditions were established with an inlet velocity of 7 m/s in the positive x-direction, while the wind turbine's rated rotational speed was set at 110 rpm, using air as the fluid medium. The blade featured dimensions including a height of 1680 mm, a diameter of 1390 mm, and a thickness of 9.5 mm. With seven blades in total, the turbine exhibited an aspect ratio of 0.78 and a blade spacing of 520 mm. These detailed specifications are fundamental to understanding both the aerodynamic performance and structural characteristics of the turbine under examination.

The simulation conducted in this paper follows a steady-transient approach, and the turbine under investigation is a Savonius drag-type turbine. Data collection points were selected at specific timesteps: timestep 4, timestep 14, timestep 28, timestep 42, timestep 56, and timestep 88. Helicity data distribution plots at timesteps 4, 28 and 56 are depicted in Figure 2, additionally plots of data at timesteps 14, 42 and 88 are illustrated in Figure 3. Helicity distribution data was collected from the mid-section of the flow domain, situated along the XZ plane.



Figure 1: Isometric view of the rotor design.

Helicity in fluid dynamics is a mathematically generated quantity that describes the degree of twist or linkage between the velocity and vorticity (rotational) fields in a fluid flow. It is often used to study the behavior of turbulence in fluid flow. Helicity denoted by H, can be calculated mathematically as follows,

$$H = \iiint (\nu \cdot \omega) d\iota$$

Where, v and  $\omega$  are the velocity vector field and vorticity vector field respectively. Vorticity vector field is nothing but curl of velocity vector field ( $\omega = \nabla \times V$ ). Triple integration signifies the entire volume of interest.

In the above equation, the dot product of velocity vector and vorticity vector is calculated at the point of interest. And then that value is integrated over the entire volume. The resulting value represents the helicity of the fluid flow. Helicity is a useful concept in fluid dynamics, especially in the study of turbulence and in situations where the twisting or linking of vortices is of interest, such as in the study of magnetic fields in astrophysics and plasma physics.

During timestep 4, the initial condition, the airflow toward the positive X axis strikes the windward concave portion of the rotor blade, leading to a very high helicity, depicted in yellow.

In contrast, the helicity at the leeward portion of the same blade is notably low, represented in blue. The blade immediately above this one exhibits very high helicity at a specific point on the leading leeward edge. The diagram at timestep 4 also reveals a region of high helicity on the right-side portion of the rotor, indicating the rotor's clockwise rotation. Similarly, on the left side of the rotor, there is a region of low helicity and spots with low-helicity regions. The right side of the rotor can be referred to as the stagnation zone, where the helicity is negligible. Closer scrutiny reveals two primary helicity fluctuations in the center portion, indicating that blades align along this line.

At timestep 14, multiple variations along the centerline are observable. These variations result from the rotation of the rotor, bringing multiple blades into contact with the airflow, leading to helicity and resulting momentum transfer. This variation from timestep 4 is an indication of the increase in rotor speed and the subsequent decrease in helicity.

At timestep 28, high-helicity regions still exist on the right side of the rotor. However, there are more concentrated lower variations of lowhelicity in regions at the concave and leading edge of the maximum blades. Some regions of low-velocity in swirling strenth can be observed on both sides of the plot. The concentration of fluctuations on both sides, in the high helicity, indicates a concentration of high stress in the rotor and rotor rotation.

At timestep 42, the reduction of fluctuation of parameter in first half of the plot can be



Figure 2: Helicity distribution plot along mid section of flow domain at time step 4, 28, 56

noticed, which indicates further decrease in the helicity in that particular points.

At timestep 56, it can be also noticed that the variation of helicity is more uniform in the flow

field. This is respected by more balanced distribution of helicity profile in the plot under study.

At timestep 88, the stress concentration in the flow field in unvarying through most portion of the flow field. Only in the extreme right side of the rotor a fluctuation indicating high helicity can be spotted. That is the thrust force which rotates the rotor in the tangential direction with the leading edge of the blade.



Figure 3: Helicity distribution plot along mid section of flow domain at timestep 14, 42, 88.

#### 3. Conclusion

It is apparent that this drag-type vertical axis wing turbine displays an adverse helicity gradient along roughly half of its blades. These regions of high helicity do not play a role in generating the overall moment. Conversely, the presence of low-helicity regions in the leeward or right half of the rotor primarily indicates lower velocity swirling strength values, indicating the dissipation of energy in the form of eddies. Nonetheless, the knowledge gleaned from this study can lay the groundwork for future optimizations of blade models and configurations. These prospective improvements hold the potential to significantly boost the efficiency of drag-type vertical axis wing turbines.

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## 70. Literature survey of evolution of vertical axis wind turbine

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#### Abstract

This paper presents a explorative study of flow field around Savonious wind turbines. This particular type of turbine is unconventional in nature for its appeal for extracting useful energy from air stream in comparison to the use of conventional wind turbines. Elementary construction, elevated startup and complete operational moment, wind adoption from any direction, ability to achieve higher angular velocity during operation, low noise production during operation, additionally, it minimizes the wear and tear on moving components, which are among the benefits of utilizing this type of machinery. Throughout the history several different adaptations for this device have been envisioned. Availability of these different configurations of rotor design is added advantage of vertical axis wind turbines. Primary objective of this study is to visualize and attempt to comprehend the variation of pressure distribution around vertical axis wind turbine (VAWT), particularly savonious type wind turbine functioning under subsonic flow condition.

Keywords: Vertical axis wind turbine (VAWT), Savonius turbine

#### 1. Introduction

In the pursuit of sustainable and renewable energy sources to meet the ever-expanding global energy demand and combat the detrimental impacts of climate change, wind power has emerged as a leading contender. For decades, conventional horizontal axis wind turbines (HAWTs) have dominated the wind energy landscape. However, the limitations associated with HAWTs, including their significant environmental footprint, intermittent energy generation, and reliance on high wind speeds, have stimulated the exploration of alternative wind energy solutions. Among these alternatives, vertical axis wind turbines (VAWTs) have emerged as a promising technology deserving of extensive research and consideration.

This paper provides a comprehensive literature review of vertical axis wind turbines, specifically focusing on the Savonius-rotor type. This system harnesses wind energy to generate electricity. In the current scenario, the use of fossil fuels leads to pollution and the release of greenhouse gases into the environment, posing significant risks to both human health and the planet. Yet, electricity is indispensable for operating electric appliances. The proposed system utilizes freely available wind energy to generate electricity and can be implemented in remote and urban areas. It has the potential to power highway lighting and electrical equipment at petrol pumps. One of the key advantages of vertical axis wind turbines is their utilization of green energy, ability to start at low wind speeds, and silent operation.

#### 2. Review and Discussions

The concept of VAWTs dates back centuries, with early designs attributed to Persian engineers and later refinements by European inventors. Despite their historical roots, VAWTs have, until recently, remained relatively overshadowed by their horizontal axis counterparts. However, recent advancements in materials, aerodynamics, and control systems have rekindled interest in VAWTs and have led to a resurgence of research and development efforts.



Figure 1: Savonius Vertical Axis Wind Turbine (Vaidya et al. 2016)

One notable subtype of VAWTs, the Savonius type wind turbine, merits special attention. The Savonius rotor, named after its Finnish inventor Sigurd Johannes Savonius, is characterized by its simple and robust design. Unlike the more common Darrieus and Darrieus-like VAWTs, which rely on lift forces to generate power, Savonius turbines harness drag forces, making them particularly suitable for low wind speed environments. This unique design features two or more curved blades mounted on a vertical axis, resembling an "S" or "U" shape, and has been a focus of interest in wind energy research for several decades. Figure 1 and 2 depicts two different type of vertical axis wind turbine, they represents example of drag-type (Savonious) and lift-type (Darrieus) vertical axis wind turbine. Figure 3 represents schematic diagram of typical helical type vertical wind turbine. Typical power curves obtained for a typical 10KW Savonious type wind turbine is shown in Figure 4.



Figure 2: The Darrieus' three-bladed vertical axis wind turbine. (Kumar et al., 2020)

Literature on Savonius-type VAWTs demonstrates their potential for low-wind-speed applications, making them ideal for use in urban and remote areas with inconsistent or modest wind resources. Their self-starting capability and ability to capture wind from any direction have made them attractive for off-grid power generation, small-scale distributed energy projects, and as a complementary technology alongside other renewable source. Researchers have explored various modifications and optimizations to enhance the performance of Savonius VAWTs, including blade shape, aspect ratio, and the addition of guide vanes, to improve their efficiency and harness a wider range of wind speeds.



Figure 3: Typical helical Savonius style VAWT. (premkumar et al., 2018)



Figure 4: Power curves for 10 KW vertical Axis Wind Turbine

Saha et al. (Saha et al., 2016) investigated the performance and stability of Savonius wind turbines in environments with low wind speed. The suitability of Savonius turbines for such critical environmental circumstances were also looked upon in their novel study. Sahin et al. (Sahin et al., 2008) focused intensely on various aspects regarding the design and manufacturing of vertical axis wind turbine blades. Their work also included the rotor design of Savonius turbine. Ashok et al (Ashok et al, 2020) discussed various recent developments and obstacles in

small-scale vertical axis wind turbines with a particular focus on Savonius turbine. A review: Altan et al (Altan et al., 2020) reviewed the techniques which can potentially enhance the performance of the Savonius turbines and other flow control devices. Thongpron et al. (Thongpron et al., 2016) experimented with Savonius wind turbines in different low wind speed conditions and analyzed the numerical results obtained from those trials. Gökçek et al. (Gökçek et al., 2011) conducted field tests, primarily focusing on wind tunnel experiments to explore the aerodynamic characteristics of helical Savonius rotors. Chen et al. (Chen et al., 2018) conducted a comprehensive analysis and assessment of different attributes pertaining to the operational efficiency of Savonius wind turbines equipped with blades featuring a helical shape. Özerdem et al. (Özerdem et al., 2007) investigated on Savonius rotors which involved conducting wind tunnel experiments and outdoor field tests to evaluate the efficiency and operational performance of Savonius rotors. Kamoji et al. (Kamoji et al., 2013) proposed strategies for enhancing the efficiency of Savonius rotors by employing twisted blades and subsequently carried out an analysis of their performance. Madavan et al. (Madavan et al., 2008) conducted an examination of how blade twist and overlap ratio influence the operational effectiveness of helical Savonius rotors. Ali et al. (Ali et al., 2020) presented a research study focusing on a customized Savonius wind turbine designed specifically for use in urban settings. Additionally, the study included both experimental and numerical investigations into this particular subject matter. Abdullah et al. (Abdullah et al., 2017) utilized finite element analysis to scrutinize the structural characteristics and integrity of Savonius rotors. This method allowed them to investigate how various forces and stresses impact the rotor's performance and durability, providing valuable insights into its mechanical behavior and potential improvements in design and materials. Rezazadeh et al. (Rezazadeh et al., 2013) conducted experimental research on Savonius rotors, with a specific focus on designing a Savonius rotor optimized for operating effectively under low wind speed conditions. Koh et al. (Koh et al., 2016) conducted a comprehensive study of Savonius wind turbines, providing an in-depth overview of their

characteristics and functioning. Their study also suggested a number of techniques and strategies for getting optimized performance from these turbines. Chauhan et al. (Chauhan et al., 2018) conducted a comprehensive review to present the effect of both the overlap ratio and blade shape on the performance of Savonius wind turbines, thereby contributing valuable perceptions for turbine design and optimization in renewable energy applications. Saha et al. (Saha et al., 2019) provided an inclusive review covering the historical evolution, present status, and potential future advancements of Savonius wind turbines. Nasiri et al. (Nasiri et al., 2020) embarked on an investigative study centered around a Savonius wind turbine, specifically engineered for urban environments where wind conditions and spatial constraints differ significantly from conventional wind energy applications using numerical simulation tools. Arul et al. (Arul et al., 2018) conducted a research study which involved a combination of experimental tests and computational simulations where they explored the impact of different overlap ratios on Savonius rotors. Ahmed et al. (Ahmed et al., 2019) focused on a research study involving both experimental and numerical analyses to investigate the aerodynamic properties of an innovative Savonius wind rotor design aimed at providing a comprehensive understanding of the rotor's airflow behavior and performance characteristics. Elkady et al. (Elkady et al., 2020) conducted a study that offers a comprehensive examination of Savonius wind turbines, incorporating both numerical simulations and experimental analyses to evaluate their operational efficiency.

#### 3. Conclusion

This literature review highlights the significance of vertical axis wind turbines (VAWTs), particularly the Savonius-type design, in the pursuit of sustainable energy sources. VAWTs offer advantages like simplicity, low wind speed efficiency, and versatility. Historically overshadowed by horizontal axis turbines, VAWTs have gained renewed attention due to their unique attributes. Savonius-type turbines, with their simple design, rapid startup, and suitability for various applications, show promise in addressing renewable energy challenges. Future research should focus
on optimizing blade models and configurations to enhance VAWT efficiency, making them more competitive in the renewable energy landscape. Overall, VAWTs, especially the Savonius type, hold great potential for a cleaner and sustainable energy future.

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# 71. A note on solution of the dispersion equation for small-amplitude internal waves in three-layer fluid

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### Abstract

This note focuses on the analysis of the nature of roots of a dispersion equation related to smallamplitude internal waves in a three-layer superposed fluid system with a free surface in the upper layer. The upper and middle layer has finite depths while the lower layer has an infinite depth. The process involves obtaining the dispersion equation and plotting the dispersion equation or related equations as functions of some relevant parameters, such as wave number, frequency, or the properties of the three fluid layers.

Keywords: Three-layer fluid, dispersion equation, real roots, contour plot.

# 1. Introduction

A wave represents a disturbance that spreads through both time and space due to the transfer of energy. When this disturbance arises from the influence of gravitational forces, it is termed as a surface gravity wave. In the realm of fluid dynamics, the dispersion of water waves typically pertains to frequency dispersion, indicating that waves of varying wave- lengths travel at distinct phase velocities. The relationship between the wave number and the angular frequency of a surface gravity wave is known as the Dispersion Equation. This terminology stems from the fact that waves, in which the speed of water propagation varies with wave number, are referred to as "dispersive" because waves of different lengths propagate at different speeds, causing them to disperse or separate. As the propagation speed of a wave component re- lies on both its wave number and angular frequency, wave dispersion constitutes a fundamental process in numerous physical phenomena. In the case of infinitely deep water, if 'k' represents the wave number and  $\omega$  is the angular frequency of a surface gravity wave, then the dispersion equation is given by

$$K = \frac{v^2}{g} \tag{1}$$

where g is the acceleration due to gravity. Equation(1) possesses the solution k = K, and this corresponds to the time-harmonic progressive surface waves represented by  $\varphi(x, y) = e^{-Ky\pm iKx}$ , where  $Re\{\varphi(x,y)e^{-i\omega t}\}$  is the velocity potential describing the two-dimensional motion in deep water occupying the position  $y \ge 0$ , the y-axis being directed vertically downwards, the plane z = 0 being the mean free surface, and the x-direction being the direction of wave propagation.

For water of uniform finite depth h, Eq. (1) modifies to the transcendental equation (cf. Wehausen and Laitone 1960, p. 474)

$$k \tanh k h = K \tag{2}$$

The transcendental equation (2) has real roots  $\pm k_0 (k_0 \ge 0)$ 

countably infinite number of purely imaginary roots  $\pm ik_n$  (n=1,2,....) where  $0 \le k_1 \le k_2$  $\leq -$  - , and  $k_n \rightarrow n\pi / h$  as  $n \rightarrow \infty$ . The positive real root  $k_0$  corresponds to progressive surface waves with wave number  $k_0$ , while the purely imaginary roots correspond to evanescent modes. The fact that the Eq. (2) has no other roots except  $\pm k_0$  and  $\pm k_n$ (n = 1, 2, ...), can be proved by employing Rouche's theorem of complex variable theory (cf. Churchill et al. 1966) to the functions  $f(k) = k \sinh kh - K \cosh kh, g(k) = k \sinh kh$ *kh* within a square with vertices k = (2m-1) $\pi(\pm 1\pm i)/2n$ , m being a large positive integer, in the complex k-plane as was demonstrated by Rhodes-Robinson (1971) for the dispersion equation in which the effect of surface tension at the free surface was included.

For two layer superposed fluids separated by a common interface, the upper fluid extending infinitely upwards and the lower fluid extending infinitely downwards, the wave number k of small amplitude interface gravity waves or internal waves is related to the angular frequency  $\omega$  by the dispersion relation (cf. Wehausen and Laitone 1960, p. 647)

$$k = \sigma K \tag{3}$$

where  $\sigma = (1+s)/(1-s)$  with  $s = \frac{\rho 2}{\rho 1}$   $(\rho_2 \ge \rho_1), \rho_1, \rho_2$ 

are the densities of the lower and upper fluids respectively. If the upper fluid is of uniform finite height h above the mean interface and has a free surface while the lower fluid extends infinitely downwards, then the corresponding equation is (cf. Linton and McIver 1995)

$$(k-K)\left\{k\left(\sigma+e^{-2\,k\,b}\right)-k\left(1-e^{-2\,k\,b}\right)\right\}=0$$
 (4)

This equation has two real roots, one is K and the other is v say, where v satisfies the equation so that

$$K\left(\sigma + e^{-2\nu h}\right) = k\left(1 - e^{-2\nu h}\right) \tag{6}$$

Thus there exist time-harmonic progressive waves with two different wave numbers K, v. An equivalent form of the Eq. (5) was given earlier in Art. 231 of the treatise by Lamb (1932) wherein a description of some of the types of wave motion which can occur in a two-layer fluid with both a free surface and an interface, was also mentioned. In this case, the dispersion equation (4) modifies to

$$k^{2}(1-s) - kK(\operatorname{coth} kb_{1} + \operatorname{coth} kb_{2}) + K^{2}(s + \operatorname{coth} kb_{1} \operatorname{coth} kb_{2}) = 0$$

$$(7)$$

This equation is given by Sherief et al. (2003, 2004) while

investigating forced gravity waves due to a plane and a

cylindrical vertical porous wave-maker in a two-layer fluid. Investigation on the nature of roots in two layer fluid has been done by D. Das et al. (2005). The linear stability for three-layer fluid has been investigated by Taylor (1931).

Several researchers studied quite a number of aspects of wave propagation in a three-layer fluid. For example, Chakrabarti et al. (2005) investigated the existence of trapped modes in a three-layer fluid channel due to a cylinder submerged in the lower layer. Das and Sahu (2021) investigated the radiation (both heave and sway) by a sphere submerged in a threelayer fluid by means of multipole expansion method. Recently, A. Das et al. (2022) investigated Radiation of water waves by a heaving submerged disc in a three-layer fluid.

### 2. Formulation

For a three layer fluid, there exist three velocity potential function  $\varphi^{I}$ ,  $\varphi^{II}$ ,  $\varphi^{II}$  and densities of upper, middle and lower layer are  $\rho_1, \rho_2, \rho_3$  ( $\rho_3 > \rho_2 > \rho_1$ ) respectively. For the completeness of this paper, we are mentioning the basic equations here. Considering the basic assumptions of linearized theory, the basic equations are derived. These functions satisfy the three-dimensional Laplace equation.

Linearized boundary conditions on the interfaces and at the free surface are

 $\nabla^2 \varphi^I = \nabla^2 \varphi^{II} = \nabla^2 \varphi^{III} = 0$ , in their respective fluid region

$$\varphi^{I}{}_{z} = \varphi^{II}{}_{z} \text{ on } z = h \tag{9}$$

$$\tilde{\mathbf{n}}_1\left(\varphi_z^I - K\varphi^I\right) = \rho_2\left(\varphi_z^{II} - K\varphi^{II}\right) \text{ on } \mathbf{z} = \mathbf{h} (10)$$

$$\varphi_{z}^{II} = \varphi_{z}^{III} \text{ on } z=0 \tag{11}$$

$$\tilde{\mathbf{n}}_{2}\left(\varphi^{II}_{\ z}-K\varphi^{II}\right)=\rho_{3}\left(\varphi^{III}_{\ z}-K\varphi^{III}\right)$$
(12)

$$\phi_{z}^{\{I\}} - K \phi_{z}^{\{I\}} = 0$$
 on  $z = h + H$  (13)

where  $=\frac{\omega^2}{g}$ . The boundary conditions (10) and (12) are the continuity of pressure at the interfaces. Finally, deep water condition yields

$$\nabla \varphi^{\{III\}} \to 0 \text{ as } z \to -\infty.$$
<sup>(14)</sup>

The dispersion equation for a three-layered fluid with the boundary conditions (8)-(14) is

$$\ddot{\mathrm{E}}(k) = (k - K)\lambda(k), \qquad (15)$$

Where

$$\lambda(k) = (k+K)\{(k+K\sigma_1)e^{\{-2kH\}} - (k-K)e^{\{-2kH\}} - (k-K\sigma_2)$$

$$\{(k+K)e^{\{-2kH\}} - (k-K\sigma_1)\}.$$
(16)

It is very important to study the other roots of this equation. It is a complicated transcendental equation and analytical solution is very difficult. In this manuscript we have adopted a graphical method to find its roots with the help of a computer software, Mathematica.

### 3. Numerical Results

It is clear from the equation (15) that k=K is a root of the equation. Our goal is to find the other roots of the equation. Since it is a complex equation, so instead of doing analytical methods, we have used numerical techniques to find the roots. Here we have plotted the contours of real and imaginary parts of  $\lambda(k) = 0$ . The points at which these two contours intersect, the real and imaginary part of  $\lambda(k)$  vanishes simultaneously. Therefore, value of  $\lambda(k)$  is zero at those points that implies these points are the roots of  $\lambda(k) = 0$ . Here, we have considered k as complex variable so that we can find roots of both real and complex nature.

In Figure 1 blue curves represents  $\text{Re}\lambda(k)$  and yellow curves represents  $\text{Im}\lambda(K)$  and red dots represents the roots of  $\lambda(k) = 0$ . Here, we have taken  $s_1=0.9$  and  $s_2=0.9$ . We considered H and h as H=0.2 and h=0.5. Here, value of K is 0.01. From this figure we can see there are two real positive roots and two real negative roots. Since we are concerned about only positive roots, this dispersion equation has exactly three roots K,  $k_1$ ,  $k_2$ . These roots K,  $k_1$ ,  $k_2$  (K <  $k_1$  <  $k_2$ ) corresponds to three different wave modes specifically at free surface, interface-I, and interface-II respectively.



Figure 1: Contour plot of  $\text{Re}\lambda(k)$  and  $\text{Im}\lambda(k)$ 

For Figure 2 we have taken value of K=0.05, while all the other parameters remains same and plotted the contours. For this case also, we can find two real positive roots. The qualitative nature of the roots does not change for different values of K. For higher values of K the value of other positive root k, is large. It is difficult to show the root graphically. Therefore, we have only plotted the graph for small values of K. For Figure 3 we have taken K = 0.05, s1=0.9, s2=0.9, h1=0.5 and h2=0.2 and plotted the contours. For this case also, we can find two real positive roots. But comparing the roots graphically it is observed that the roots have slightly shifted to the right side of the real axis. Therefore if we take H > h, magnitude of the roots increases i.e. the wave numbers increases for both the internal waves.



Figure 2: Contour plot of  $\text{Re}\lambda(k)$  and  $\text{Im}\lambda(k)$ 



**Figure 3:** Contour plot of  $\text{Re}\lambda(k)$  and  $\text{Im}\lambda(k)$ 

### 4. Conclusion

In the present study we have discussed about the dispersion equation in three layer fluid in the context of linearized water wave theory and our main focus is to determine the nature of the roots of the dispersion equation that arises in this kind of problems. Here we have plotted the contour graphically and we can see that there are only three positive real roots, no-other roots are there. For higher values of K the value of other positive roots increases and for H > h, value of root also increases.

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# 72. A small note on the dispersion equation and it's roots forwaves in mangrove forests in presence of surface tension

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### Abstract

The effect of a thin viscoelastic mud layer on the wave propagation through mangrove forests has been analyzed within the framework of linear water wave theory. In this two dimensional problem the trunks and roots are assumed to be in the upper water layer and roots are assumed to be in the thin mud layer. The dispersion relation between the wave frequency and the wave number has been obtained and the attenuation rate has been computed. The effects of the physical parameters like viscosity and elasticity of the mud, density of the forest, depth of the mud has been analyzed in the context of attenuation and propagation of waves. The present model will be a realistic and significant approach to understand the water wave propagation through mangrove forests.

Keywords: Mangrove forest, surface tension, dispersion equation, wave attenuation.

# 1. Introduction

The current substantial increase in sea levels presents a significant concern. Between 1993 and 2017, there was a recordedrise of 7.5 cm in sea level. If this trend persists, it poses a severe threat to numerous coastal areas, including major cities. The destructive impact of cyclonic sea storms and other natural disasters such as tsunamis endangers all life forms in these regions. Consequently, coastal protection stands as one of our most pressing challenges today. To address this issue, one of the most straightforward solutions is to plant mangroves along the coastlines.

The complex nature of mangrove ecosystems has often posed challenges in comprehending the way waves propagate through these areas. Mazda et al. (1997) delved into the relationship between the drag coefficient and various Reynolds numbers, exploring how the number and diameters of tree trunks change at varying distances from the sea bottom. Massel et al. (1999) took a linearized approach to the governing equations governing motion within mangrove forests. Hadi et al. (2003) further scrutinized this model, assessing its efficacy in wave attenuation by applying it to two different types of mangrove forests, specifically Rhizophora and Ceriops.

In their thesis, Brinkman (2006) developed a model for wave propagation through non-uniform mangrove forests, while Vo-Lounge and Massel (2008) examined non-uniform forests with arbitrary depths, considering the bottom as an inclined surface. Mei et al. (2011) formulated a model treating the forest as an array of vertical cylinders and investigated the propagation of long surface waves through these forested areas. Recently, the study on mangrove forest has gained significant importance from researchers (Das et al. 2022).

All of these aforementioned studies were carried out with- out considering the effect of surface tension on wave generation. However surface tension plays an important role in wave propagation. Actually, the amplitude and frequency of the waves depend on both the surface tension and gravity. The effect of surface tension has been incorporated by many authors in other classes of problems. (cf. Rhodes-Robinson 1982, see Lamb 1924). In the present study, the suraface tension have been incorporated to study wave propagation in mangrove forests. The dispersion equation have been obtained and analyzed using numerical methods and the effect on wave attenuation has been studied.

### 2. Formulation

Within the framework of linear theory, the motion is considered to be inviscid, incompressible and homogeneous with constant volume density  $\rho$  under the action of gravity g only and bounded above by a free surface. A rectangular Cartesian co-ordinate system is chosen in which the  $\gamma$ -axis is taken vertically downwards and the plane y = 0 is the position of the undisturbed free surface. Water occupies the region  $y \ge 0$ or  $0 \le y \le h$  according as it is of finite depth or of uniform finite depth h. Massel et al. (1999) described the governing equation inside of a mangrove forest. Here, the derivation has been given briefly for the sake of completeness. Wave motion within the mangrove forest is subjected to strong dissipation due to the multiple interactions with mangrove trunks and bottom friction. Hence, the momentum equation for motion with dissipation can be written as follows:

$$\frac{\partial u}{\partial t} = \frac{1}{\rho} \nabla \left( \mathbf{p} + \rho g \mathbf{y} \right) - \frac{1}{\rho} F \tag{1}$$

in which u = (u; v) is the wave-induced velocity vector, p is the corresponding dynamic pressure and F is the force vector (per unit volume).

The total F force (per unit volume), can be represented as follows:(cf. Massel 1999)

$$F(x,y) = \frac{1}{2} \rho \overline{D \sum_{j=1}^{N} C_{d}^{(m)}(Re) u_{n,j}(x,y)} |u_{n,j}(x,y)|$$
(2)

The vector  $u_{n,j}(x,y)$  is the water velocity, normal to the longitudinal axis of the particular trunk or root j induced by wave orbital velocity u = (u; v); D is the mean diameters of trunks and roots and N is the number of roots and trunks.

The coefficient  $C_d^{(m)}(\text{Re})$  is basically function of the Reynolds number Re and it is introduced

to parameterize the interaction between roots and trunks. The following dependency of  $C_d^{(m)}$ (Re) on Re is assumed:

$$C_{d}^{\{(m)\}} = \begin{cases} 1.2 & Re \le 2 \times 10^{5} \\ 1.2 - 0.5 \left(\frac{Re}{3 \times 10^{5}} - \frac{2}{3}\right) & 2 \times 10^{5} \le Re \le 5 \times 10^{5} \\ 0.7 & Re \ge 5 \times 10^{5} \\ \end{cases}$$
(3)

The nonlinear term in Equation (1) was replaced by the linear one under the condition that the mean error  $\varepsilon$  of this substitution becomes minimal, i.e.:

$$\frac{1}{\rho}F \approx f_e \omega_p u(x, y) \tag{4}$$

and

$$\mathbf{a} = \frac{1}{\rho} F - f_e \omega_p u(\mathbf{x}, \mathbf{y}) \tag{5}$$

The linearization procedure is based on the concept of minimalization in the stochastic sense. Thus, we have

$$\int_{\{0\}}^{\{b\}} \int_{\{0\}}^{\{l\}} \mathcal{E}\left[\dot{\mathbf{o}}^{2}\right] dx dy = minimum \tag{6}$$

Thus equation (1) becomes

$$\frac{\partial u}{\partial t} = \frac{1}{\rho} \nabla \left( \mathbf{p} + \rho g \mathbf{y} \right) - \frac{1}{\rho} f_e \omega_p u(\mathbf{x}, \mathbf{y}) \tag{7}$$

As the motion is considered to be irrotational  $q = \nabla \emptyset$ . (8)

Therefore the equation of continuity becomes

$$\nabla^2 \varnothing = 0 \quad in the fluid region \tag{9}$$

Modified Euler's equation of motion reduces to

$$\frac{\partial \emptyset}{\partial t} = g y - \frac{p}{\rho} - f_e \omega_p \emptyset \text{ in the fluid region} \quad (10)$$

where p is the pressure and  $\rho$  is the density of water. In particular, at the sea surface after incorporating the effect of surface tension, we have

$$\frac{\partial \emptyset}{\partial t} = g \, y - \frac{p}{\rho} - f_e \omega_p \emptyset - \frac{T}{\rho} \eta_{xx} \tag{11}$$

where T is surface tension component. At sea bottom (y = h) we assume that the bottom is impermeable, i.e.,

$$\frac{\partial \emptyset}{\partial y} = 0 \qquad on \, y = h \tag{12}$$

For a time harmonic motion with angular frequency  $\omega$  the governing equations can be written as follows

$$\nabla^2 \varphi = 0$$
 in the fluid region (13)  
And

$$\frac{\partial \varphi}{\partial y} = 0 \qquad on \, y = b \tag{14}$$

Differentiating equation (11) w.r.t. t and after simplification we get

$$K\left(1+i\frac{f_e\omega_p}{\omega}\right)\varphi + \frac{\partial\varphi}{\partial y} + M \varphi_{yyy} = 0 \text{ on } y = 0$$
(15)

Where K = 
$$\frac{\omega^2}{g}$$
 and M =  $\frac{T}{\rho g}$ 

### 3. Solution

The complex valued potential  $\varphi$  satisfy the Laplace equation (13). By using separation of variables this equation can be solved. Taking  $\varphi = X(x)Y(y)$ .

Then X(x) satisfies the following equation

$$\frac{d^2 X(x)}{dx^2} = +k X(x) = 0$$
(16)

and Y (y) satisfies

$$\frac{d^2Y(y)}{dy^2} = +kY(y) = 0$$
(17)



Figure 1: Contour plot of  $Re\lambda(k)$  and  $Im\lambda(k)$ 

Therefore using condition (14) and (15) the solution can be written as

$$\varphi(x,y) = \frac{\cosh k (h-y)}{\cosh k h} e^{ikx}$$
(18)

where k satisfies the following dispersion equation

$$k(1+Mk^2)\tanh kb = K(1+i\frac{f_e\omega_p}{\omega})$$
(19)

Therefore, the roots of the equation (19) completely defines the nature of wave propagation inside a mangrove forest. As the dispersion equation has complex numbers, it is not possible to find its roots analytically using graphical method.

Consequently, in this paper the roots have been found using computer algorithms.



Figure 2: Contour plot of  $Re\lambda(k)$  and  $Im\lambda(k)$ 

# 4. Numerical Results

For the numerical computations, the parameters are kept fixed as fe=0.1, h=1, M=0.001;  $\omega = 0.8$ (after after non dimensionalize). The linearising coefficient fe=0.1 corresponds to a forest of width 50 m, where the number of trunks in upper layer is 1/m<sup>2</sup> and number of trunks in lower layer is 9/m<sup>2</sup>. The linearising coefficient fe= 0.3 corresponds to number of trunks in upper layer 16/m<sup>2</sup> and 49/m<sup>2</sup> in lower layer with a mean diameter 0.08 m in upper layer and 0.02 m in lower layer. Clearly, the equation (19) cannot have any real roots or purely imaginary roots. All the roots of equation (19) are complex numbers. The primary idea of the position of the roots have been obtained by plotting the contours of  $\text{Re}\{\lambda(k)\} = 0$  and  $\text{Im}\{\lambda(k)\} = 0$  where  $k(1 + M k^2) \tanh kh - K(1 + i fewp \omega) = 0$ . Here the point of intersections where both real and imaginary parts vanishes are the roots of the equation (19).



Figure 3: Contour plot of  $Re\lambda(k)$  and  $Im\lambda(k)$ 

In Figure 1, the contours have been plotted for  $\omega$ =0.1.

It is observed that though the roots are complex numbers but they are very close to the roots of the dispersion equation for a single layer fluid with rigid bottom. The root that is situated very close to real axis associated with the propagating wave, but as the root is complex number, the small imaginary part will help to attenuate the wave.

Figure 2 have been plotted for  $\omega = 0.8$  while all other parameters remains same. As the velocity increases the corresponding wavenumber also increases but with that its complex part also increases. Consequently the propagating wave will attenuate faster. Therefore, it can be concluded that the waves with high frequencies will attenuate more rapidly while passing through the mangrove forests. Figure 3 depicts the contours for relatively higher values of fe. Here, fe = 0.3 have been chosen. It can be observed that the roots are significantly away from both real axis and imaginary axis. It indicates that the wave will attenuate rapidly.

### 5. Conclusion

In the present study, the roots of the dispersion equation have been studied that arises during the study wave propagation in mangrove forest. The presence of surface tension is also considered. The dispersion equation is a transcendental equation with complex coefficient. Therefore instead of using analytical methods, graphical method have been used to locate the roots. It is interesting to note that the waves with higher frequencies will attenuate faster than a wave with small frequency. Also, roots of the dispersion equation agrees with the conclusion that the denser mangrove forests will attenuate the waves faster.

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# 73. Dissipative solitons in magnetized pair-ion plasmas

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### Abstract

Magnetosonic wave has been studied in a magnetized pair-ion plasma consisting of positive and negative ions of equal masses in the presence of positive (negative) ion-neutral collisions. The applied magnetic field lies perpendicular to the wave propagation. The standard reductive perturbative technique approach leads to a Korteweg-de Vries equation with a linear damping term for the dynamics of the finite amplitude wave. The dissipation in the system comes from the ion-neutral collision, which is responsible for the linear damping. The time-dependent analytic solution reveals that the soliton amplitude, energy, and velocity decrease exponentially, whereas soliton width increases exponentially with time. The numerical simulation yields the same result as the analytical.

Keywords:Magnetosonic solitary waves, Magnetosonic waves, Standard reductive perturbative technique

# 1. Introduction

In recent years, the study on pair plasmas consisting of positive and negative charge particles of equal mass has received intensive attention theoretically(Dubin 2004, Iwamoto 1993, Mofiz 1989, Kourakis et al. 2006, Zank 1995) and experimentally(Surko at. al. 1989, Greaves at. al. 1994). Pair plasmas represent a new class with unique properties remarkably different from conventional electron-ion plasma. For example, the equality in the mass of both species of pair plasmas gives space-time symmetry and the same mobility of charged particles in an electromagnetic field, allowing us to analyze new collective modes in pair plasmas in contrast to the conventional plasma with a huge mass difference. Electron-positron (e-p) plasmas are one type of pair plasmas consisting of electron and positron. Such plasmas exist in various astrophysical plasma situations, such as active galactic nuclei, neutron stars, quasars, and pulsar magnetospheres(Michel 1991, Miller and Witta 1987).

Many investigations have been done by various authors(Ghosh at. al. 2014, Sikdar at. al. 2018, Adak at. al. 2015, Verheest and Cattaert 2005)to study the nonlinear collective modes in pure pair-ion plasmas (without electrons) in the presence and absence of a magnetic field. In the presence of a magnetic field, the propagation of magnetosonic waves represents one of the most important modes in plasma research. The time evolution of nonlinear magnetosonic waves propagating obliquely to the magnetic field in plasmas is governed by the Korteweg de Vries (KdV) equation(Ohsawa 1985,Ohsawa 1986) or Korteweg de VriesBergers' (KdVB) equation (in the presence of collision) (Kawahara 1970) Kadomtsev-Petviashvili-Burgers' equation or (two-dimensional case) (Janakiet al. 1991). In pair plasmas, many authors have studied the magnetosonic waves in the presence of electron impurity(Shisenet al. 2013, Hussain and Hasnain 2017).

This paper aims to investigate the nonlinear localized structures of magnetosonic waves in small amplitude limits in magnetized pair-ion plasmas in the presence of ion-neutral collisions. The external magnetic field is applied perpendicular to the wave propagation. We have considered a two-fluid model to describe the dynamics for pair-ion plasmas consisting of only positive and negative ions with equal mass. In the finite-amplitude limit, employing the well-known reductive perturbation technique (RPT), we have derived a Korteweg de Vries (KdV) equation with a linear damping term. Here, the linear damping term arises due to the ion-neutral collision. The damped KdV equation has been solved both analytically and numerically. In both cases, weakly dissipative magnetosonic solitary waves have been found. In the presence of weak ion-neutral collision, the soliton amplitude, energy, and velocity decrease exponentially, and the soliton width increases exponentially.

This paper is organized as follows: In Sec. II, physical assumptions, and the complete set of two-fluid equations are described. The linear dispersion relation of the magnetosonic wave is derived in Sec. III. In Sec. IV, the damped KdVequation is derived using RPT in a small amplitude limit. In Sec. V, an approximate analytical solution of the damped KdVequation is derived and verified by the numerical simulation in Sec. VI. Finally, we have concluded our results in Section VII.

# 2. Physical Assumptions and Basic Equations

We have considered a homogeneous magnetized pair-ion plasma consisting of positive and negative fullerene ions  $(C_{60}^{\pm})$  in the presence of ion-neutral collision. The external magnetic field is applied in the  $e_z$  direction. As per the experimental observation(Ooharaet al. 2005, Ooharaet al. 2007), the masses of both ions are identical, i.e.,  $m_+ = m_- = m$  (say) (where  $m_{\pm}$  is the positive (negative) ion mass) as they generated from same source (fullerene ion source), but slightly different (range of (0.3 - 0.5) eV) in temperature due to the other charging processes of both the positive and negative fullerene ions, therefore,  $T_+ \neq T_-$  (where  $T_{\pm}$  is the positive (negative) ion temperature). The plasma is overall quasi-neutral. In equilibrium, we have assumed the quasi-neutrality condition for singly charged ions, i.e.,  $n_{+0} = n_{-0} = n_0$  (say), where  $n_{\pm 0}$  is the equilibrium number density of positive (negative) ions.

The following equations are the basic momentum equations for both ions

$$mn_{\pm} \left( \frac{\partial}{\partial t} + \mathbf{u}_{\pm} \cdot \nabla \right) \mathbf{u}_{\pm} = \pm en_{\pm} \left( \mathbf{E} + \frac{1}{c} \mathbf{u}_{\pm} \times \mathbf{B} \right) \quad (1)$$
$$-\nabla p_{\pm} - mn_{\pm} v_{\pm n} \mathbf{u}_{\pm}$$

the continuity equations for both ions

$$\frac{\partial n_{\pm}}{\partial t} + \nabla \cdot \left( n_{\pm} \mathbf{u}_{\pm} \right) = 0 \tag{2}$$

and the following Maxwell's equations

$$\frac{\partial \mathbf{B}}{\partial t} = -c\nabla \times \mathbf{E} \tag{3}$$

$$\nabla \times \mathbf{B} = \frac{4\pi e}{c} \left( n_+ \mathbf{u}_+ - n_- \mathbf{u}_- \right), \tag{4}$$

where  $\pm$  stands for positive/negative ions and  $V_{+n}$  is positive(negative) ion - neutral collision frequency. All other variables are in the usual notation. This study investigates the collective behavior of magnetosonic waves in pair-ion plasmas in the presence of ion-neutral collision. To incorporate the effects of collisions, we assume that the ion-neutral collision frequency  $(v_{\pm n})$  is much smaller than the cyclotron frequency of ions  $(\omega_c)$ , i.e.,  $v_{\pm n} \ll \omega_c$ . We have assumed the equation of state is adiabatic so that  $p_{\pm} = C n_{\pm}^{\gamma}$ , where C is a constant,  $\gamma = \frac{N+2}{N}$  is the adiabatic index and N = 3. Combination of this assumption and the equation of state at equilibrium  $p_{\pm 0} = n_0 T_{\pm}$ , the pressure term may be rearranged as  $\nabla p_+ = \gamma T_+ n_0^{1-\gamma} n_+^{\gamma-1} \nabla n_+$ .

Furthermore, we have assumed that the propagation of the magnetosonic wave is carried out only in one space variable x (say), i.e.,  $\nabla \equiv \hat{e}_x \left(\frac{\partial}{\partial x}\right)$  and all variables are functions of x and t. Therefore, the external magnetic field (**B**), electric field (**E**) and

the ion velocity  $(\mathbf{u}_{\pm})$  can be expressed as  $\mathbf{B} = B(x,t)e_z, \mathbf{E} = E_x(x,t)e_x + E_y(x,t)e_y$  and  $\mathbf{u}_{\pm} = u_{\pm x}(x,t)e_x + u_{\pm y}(x,t)e_y$ , respectively. For the sake of simplicity, we have normalized the basic equations (1)-(4) in the following manner:  $\hat{t} = \left(\frac{V_A}{L}\right)t, \hat{x} = \frac{x}{L}, \hat{n} = \frac{n}{n_0}, \hat{\mathbf{u}}_{\pm} = \frac{\mathbf{u}_{\pm}}{V_A},$   $\hat{\mathbf{E}} = \left(\frac{e\mathbf{E}}{mV_A\omega_c}\right)$  and  $\hat{\mathbf{B}} = \frac{\mathbf{B}}{B_0}$ , where  $B_0$  is the magnitude of the magnetic field, the cyclotron frequency  $\omega_c = \frac{eB_0}{mc}$ , the Alfvén velocity  $U_c = \frac{B_0}{mc}$  and L is the system length

ty  $V_A = \frac{B_0}{\sqrt{8\pi m n_0}}$  and L is the system length.

Therefore, the normalized  $e_x$  and  $e_y$  components of momentum equations for positive/ negative ions are

$$\begin{pmatrix} \frac{\partial}{\partial t} + u_{\pm x} \frac{\partial}{\partial x} \end{pmatrix} u_{\pm x} = \pm \frac{1}{\sqrt{D}} \left( E_x + u_{\pm y} B \right)$$

$$- M^2 \sigma_{\pm} n_{\pm}^{-\frac{1}{3}} \frac{\partial n_{\pm}}{\partial x} - v_{\pm} u_{\pm x}$$

$$(5)$$

and

$$\left(\frac{\partial}{\partial t} + u_{\pm x}\frac{\partial}{\partial x}\right)u_{\pm y} = \pm \frac{1}{\sqrt{D}}\left(E_{y} - u_{\pm x}B\right) - v_{\pm}u_{\pm y}, \quad (6)$$

respectively, and the continuity equation for positive/negative ions are

$$\frac{\partial n_{\pm}}{\partial t} + \frac{\partial}{\partial x} \left( n_{\pm} u_{\pm x} \right) = 0 \tag{7}$$

The  $e_z$  component of Faraday's law is

$$\frac{\partial E_{y}}{\partial x} = -\frac{\partial B}{\partial t} \tag{8}$$

The  $e_x$  and  $e_y$  of Ampere's law are

$$0 = n_{+}u_{+x} - n_{-}u_{-x} \tag{9}$$

and

$$2\sqrt{D}\frac{\partial B}{\partial x} = n_{-}u_{-y} - n_{+}u_{+y} \tag{10}$$

respectively. In the above equations, the physical parameter  $\sigma_{\pm} = T_{\pm} / T$ ,  $M = C_s / V_A$ ,  $D = (\delta / L)^2$ 

and  $v_{\pm} = \frac{v_{\pm n}}{\omega_c \sqrt{D}}$ , where  $C_s$  is the acoustic speed defined by  $C_s = (\gamma T / m)^{\frac{1}{2}}$  and  $\delta = \frac{mc}{\sqrt{8\pi mn_0 e^2}}$ is skin depth. Here, we define a new temperature variable  $T = \frac{(T_+ + T_-)}{2}$ . We have written the normalized variables without the hat sign for simplicity in writing the above-normalized equation (5)-(10).

### 3. Linear Analysis

We proceed by considering the perturbations of the dynamical variable  $(n_{\pm}, u_{\pm x}, u_{\pm y}, E_x, E_y, B)$ of the form  $\sim \exp i(kx - \omega t)$ , where  $\omega$  is the frequency and k is the wave number. From the linearized eqs. (5)-(10), we obtained the general linear dispersion relation as

$$a\omega^4 + ib\omega^3 - c\omega^2 - id\omega + e = 0 \tag{11}$$

where

$$a = 1 + k^{2}D, b = (2 + 3k^{2}D)v, e = v_{+}v_{-}M^{2}k^{2}D,$$
  

$$c = (M^{2}a + 1)k^{2} + (2k^{2}D + 1)v^{2} + v_{+}v_{-}k^{2}D,$$
  

$$d = (2k^{2}D + 1)vM^{2}k^{2} + (v_{+}v_{-}D + 1)vk^{2}$$

Here, we define a new constant  $v = \frac{(v_+ + v_-)}{2}$ . In the absence of ion-neutral collision  $(v_+ = 0 = v_-)$ , the above dispersion relation reduces to the dispersion relation of magnetosonic wave in pair-ion plasmas, which is given below:

$$\omega^{2} = C_{s}^{2}k^{2} + \frac{V_{A}^{2}k^{2}}{1 + \delta^{2}k^{2}}$$
(12)

in dimensional form, where  $\delta = \frac{mc}{\sqrt{8\pi mn_0 e^2}}$ 

is skin depth, it arises due to the finite inertia of negative or positive ions. The finite inertia of negative or positive ions acts as a source of dispersion of magnetosonic waves in pair-ion plasmas. As a result, the parameter D represents the dispersion in the system. For the single fluid case (e.g., magnetohydrodynamics model),  $\delta$ should be zero. Therefore, there should not be any dissipation in the system. The above linear dispersion relation eq. (11) is solved numerically and plotted in Figures1 and 2. A graphical representation of the linear dispersion equation of magnetosonic wave in the absence of ion-neutral collision has been depicted in Figure1. Real  $(\omega_r)$  and imaginary  $(\omega_i)$  part of the dispersion relation eq. (11) has been depicted in Figure2 in the presence of collisions against the wave number k. The real part shows the usual characteristic of a magnetosonic wave, and the imaginary part shows the damping rate of the wave concerning wave number k.



**Figure 1** Graphical representation of dispersion relation (11) in absence of ion-neutral collisions  $(\nu_+ = 0 = \nu_-)$ . The plasma parameters are D=1.0 and M=0.94.



Figure 2: Graphical representation of dispersion relation (11) in presence of ion-ion collisions. Here,  $\omega_r$  and  $\omega_i$  are the real and imaginary

parts of the wave frequency  $\omega$ , respectively. The plasma parameters are  $v_+=0.02$ ,  $v_+=0.03$ , D=1.0 and M=0.94.

### 4. Nonlinear Wave Equations

To investigate the propagation characteristic of magnetosonic waves in pair-ion plasmas in the presence of ion-neutral collision, we have employed the reductive perturbation technique and, therefore, introduced the following stretched coordinates:

$$\xi = \dot{\mathbf{o}}^{\frac{1}{2}} \left( x - \lambda t \right), \tau = \dot{\mathbf{o}}^{\frac{3}{2}} t, \qquad (13)$$

where  $\lambda$  is the normalized phase velocity of the linear propagated wave and  $\hat{o}(\ll 1)$  is a small real parameter that characterizes the strength of the nonlinearity. The physical variables and *B* are expanded in the power series of  $\hat{o}$  as follows:

$$\begin{aligned} n_{\pm} &= 1 + \epsilon n_{\pm}^{(1)} + \epsilon^2 n_{\pm}^{(2)} + \cdots, \\ u_{\pm x} &= 0 + \epsilon u_{\pm x}^{(1)} + \epsilon^2 u_{\pm x}^{(2)} + \cdots, \\ u_{\pm y} &= 0 + \epsilon \sqrt{\epsilon} u_{\pm y}^{(1)} + \epsilon^2 \sqrt{\epsilon} u_{\pm y}^{(2)} + \cdots, \\ E_x &= 0 + \epsilon \sqrt{\epsilon} E_x^{(1)} + \epsilon^2 \sqrt{\epsilon} E_x^{(2)} + \cdots, \\ E_y &= 0 + \epsilon E_y^{(1)} + \epsilon^2 E_y^{(2)} + \cdots, \\ B &= 1 + \epsilon b^{(1)} + \epsilon^2 b^{(2)} + \cdots. \end{aligned}$$
(14)

To include the collisional effect and also for the consistent perturbation, we have assumed that  $v_{\pm} = \frac{v_{\pm n}}{\omega_c \sqrt{D}}$  is of the order of  $\epsilon \sqrt{\epsilon}$ which is also compatible with our assumption  $v_{\pm n} \ll \omega_c$  as  $\epsilon$  is a small real quantity. Now, substitute this assumption, the stretched coordinate (Eq. (13)) and the expanded physical variables (Eq. (14)) into the basic Eqs. (5)-(10), from the lowest order of of each equation, we obtain the following relations:

$$-\lambda \frac{\partial u_{\pm x}^{(1)}}{\partial \xi} = \pm \frac{1}{\sqrt{D}} \left( E_x^{(1)} + u_{\pm y}^{(1)} \right) - M^2 \sigma_{\pm} \frac{\partial n_{\pm}^{(1)}}{\partial \xi}$$
(15)

$$E_y^{(1)} = u_{\pm x}^{(1)},$$
 (16)

$$\frac{\partial u_{\pm x}^{(1)}}{\partial \xi} = \lambda \frac{\partial n_{\pm}^{(1)}}{\partial \xi}, \qquad (17)$$

$$\frac{\partial u_{\pm x}^{(1)}}{\partial \xi} = \lambda \frac{\partial n_{\pm}^{(1)}}{\partial \xi}, \qquad (18)$$

$$u_{-x}^{(1)} = u_{-x}^{(1)},$$
 (19)

$$2\sqrt{D}\frac{\partial b^{(1)}}{\partial \xi} = u_{-y}^{(1)} - u_{+y}^{(1)}, \qquad (20)$$

From the above equations, we obtain the following relations:

$$n_{\pm}, u_{\pm x}, u_{\pm y}, E_{x}, E_{y} \dot{\mathbf{o}} \qquad u_{\pm x}^{(1)} = u_{-x}^{(1)} = u^{(1)} (\text{ say}), \\ n_{\pm}^{(1)} = n_{-}^{(1)} = n^{(1)} (\text{ say}), \\ E_{y}^{(1)} = \lambda b^{(1)} = u^{(1)} = \lambda n^{(1)}.$$

$$(21)$$

Using these relations from Eqs. (15) and (20), we obtain the phase velocity of the linear wave as follows:

$$\lambda^{2} = 1 + \left(\frac{\sigma_{+} + \sigma_{-}}{2}\right)M^{2} = 1 + M^{2},$$
 (22)

where  $\frac{(\sigma_+ + \sigma_-)}{2} = 1$  according to the definition of  $\sigma_{\pm}$ . This relation (Eq. (22)) readily recovers the dispersion relation of magnetosonic wave in dimensional form as:  $\omega^2 = (V_A^2 + C_s^2)k^2$ .

Now, from the next higher order of feqs. (6) and (9) we obtain

$$-\lambda \frac{\partial u_{\pm y}^{(1)}}{\partial \xi} = \pm \frac{1}{\sqrt{D}} \Big( E_y^{(2)} - u_{\pm x}^{(2)} - b^{(1)} u_{\pm x}^{(1)} \Big) \quad (23)$$

$$u_{+x}^{(2)} + n^{(1)}u_{+x}^{(1)} = u_{-x}^{(2)} + n^{(1)}u_{-x}^{(1)}$$
(24)

This gives

$$u_{+x}^{(2)} = u_{-x}^{(2)} = u^{(2)}(\text{ say })$$
 (25)

$$\lambda D \frac{\partial^2 b^{(1)}}{\partial \xi^2} = E_y^{(2)} - u^{(2)} - \lambda b^{(1)^2}, \quad (26)$$

$$\lambda \frac{\partial}{\partial \xi} \left( u_{+y}^{(1)} + u_{-y}^{(1)} \right) = 0 \tag{27}$$

Eq. (27) enables us to find the value of  $u_{+y}^{(1)}, u_{-y}^{(1)}$  from Eq. (15) as

$$u_{+y}^{(1)} = \sqrt{D} \left( M^2 \sigma_+ - \lambda^2 \right) \frac{\partial n^{(1)}}{\partial \xi} - E_x^{(1)}, \qquad (28)$$

$$u_{-y}^{(1)} = -\sqrt{D} \left( M^2 \sigma_{-} - \lambda^2 \right) \frac{\partial n^{(1)}}{\partial \xi} - E_x^{(1)} \quad (29)$$

where,

$$E_x^{(1)} = \sqrt{D}M^2 \left(\frac{\sigma_+ - \sigma_-}{2}\right) \frac{\partial n^{(1)}}{\partial \xi}$$
(30)

Now, from next higher order of  $\dot{o}$  of each equation other than Eqs. (6) and (9) we obtain

$$\frac{\partial u^{(1)}}{\partial \tau} - \lambda \frac{\partial u^{(2)}}{\partial \xi} + u^{(1)} \frac{\partial u^{(1)}}{\partial \xi} = \\ \pm \frac{1}{\sqrt{D}} \Big( E_x^{(2)} + u_{\pm y}^{(2)} + u_{\pm y}^{(1)} b^{(1)} \Big) \\ -M^2 \sigma_{\pm} \frac{\partial n_{\pm}^{(2)}}{\partial \xi} + \frac{1}{3} M^2 \sigma_{\pm} n^{(1)} \frac{\partial n^{(1)}}{\partial \xi} - \nu_{\pm} u^{(1)}$$
(31)

$$\frac{\partial n^{(1)}}{\partial \tau} - \lambda \frac{\partial n_{\pm}^{(2)}}{\partial \xi} + \frac{\partial u^{(2)}}{\partial \xi} + \frac{\partial}{\partial \xi} \left( n^{(1)} u^{(1)} \right) = 0 \qquad (32)$$

$$\frac{\partial E_{y}^{(2)}}{\partial \xi} = -\frac{\partial b^{(1)}}{\partial \tau} + \lambda \frac{\partial b^{(2)}}{\partial \xi}$$
(33)

$$2\sqrt{D}\frac{\partial b^{(2)}}{\partial \xi} = u_{-y}^{(2)} - u_{+y}^{(2)} + n^{(1)}\left(u_{-y}^{(1)} - u_{+y}^{(1)}\right)$$
(34)

Finally, eliminating  $n_{\pm}^{(2)}, u^{(2)}, u_{\pm y}^{(2)}$  and  $E_x^{(2)}$  from the equations (31)-(34), we obtain the following damped Korteweg -de Vries (dKdV) equation with  $\left[n^{(1)} = \psi\right]$ :

$$\frac{\partial\psi}{\partial\tau} + \alpha\psi \frac{\partial\psi}{\partial\xi} + \beta \frac{\partial^3\psi}{\partial\xi^3} + \frac{\nu}{2}\psi = 0$$
(35)

where  $\alpha, \beta$  and  $\nu$  are as follows:

$$\alpha = \frac{9 + 8M^2}{6\sqrt{1 + M^2}}, \beta = \frac{D}{2\sqrt{1 + M^2}},$$

$$v = \frac{(v_+ + v_-)}{2}.$$
(36)

The coefficients  $\alpha$  represents the nonlinearity,  $\beta$  represents the dispersion and  $\nu$  represents the linear dissipation of the wave. It is clear from Eq. (35) that the linear damping term arises from both positive and negative ion-neutral collisions. In absence of ion-neutral collisions, i.e.,  $\nu_{\pm} = 0$ , the linear damping coefficient  $\nu = 0$ . Therefore, in that case one can get only a usual KdV equation which possesses solitary wave.

### 5. Analytical Solutions

The exact analytical solution of the damped KdV Eq. (35) is not possible as it is not a completely integrable Hamiltonian system(Jeffery and Kakutani 1972, Belashov and Vladimirov 2005) Therefore, the energy ( $\mathcal{E}$ ) of the system is not conserved. The conservation of energy equation of the damped KdVEq. (35) is following:

$$\frac{\partial \mathcal{E}}{\partial \tau} = -v\mathcal{E}, \text{ where } \mathcal{E} = \int_{-\infty}^{\infty} \psi^2 \left(\xi, \tau\right) d\xi, \quad (37)$$

with the boundary condition  $\psi(\xi,\tau), \partial_{\xi}\psi(\xi,\tau)$  and  $\partial_{\xi}^{2}\psi(\xi,\tau)$  all  $\rightarrow 0$ 

as  $|\xi| \rightarrow \infty$ . In absence of ion-neutral collisions the soliton energy is conserved and the Eq. (35) [with ] yields the single soliton solution

$$\psi(\xi,\tau) = \emptyset \operatorname{sech}^2 \sqrt{\frac{\alpha\emptyset}{12\beta}} \left(\xi - \frac{\alpha\emptyset}{3}\tau\right),$$
(38)

where  $\emptyset = \frac{3U}{\alpha}$  is the soliton amplitude,  $U_{1}$ is the soliton velocity and  $L = (\alpha \emptyset / 12\beta)^{-2}$ is the spatial width of the soliton. From the soliton solution [Eq.(38)], one can establish the well-known KdV properties that amplitude  $(\emptyset) \times \text{width}^2 (L^2) = \frac{12\beta}{\alpha} = \text{constant}$ is always maintained for fixed plasma parameters. This solution has been plotted in Figure3(a) with respect to space for different time. It shows the propagation of magnetosonic solitary waves without any change in shape and size with respect to time. In the presence of linear damping term  $(v \neq 0)$ , an approximate solution can be obtained by perturbation analysis(Newell 1985) for a weak dissipation case  $(\nu \ll 1)$ . For that purpose, we have assumed that the slow

time dependent form of the soliton amplitude, i.e.,  $\emptyset = \emptyset(\tau)$ . Moreover, we have considered the single soliton solution of the damped KdV equation (Eq. (35)) in this perturbation analysis(Newell 1985) is as follows:

$$\psi(\xi \mathbf{\mathcal{D}}) = \operatorname{se}(\mathbf{h}) \qquad {}^{2} \sqrt{\frac{\alpha \mathcal{O}(\tau)}{12\beta}} \left( \xi - \frac{\alpha}{3} \int_{0}^{\tau} {\binom{v}{\tau}} d \frac{v}{\tau} \right) (39)$$

where 
$$\left(\frac{\alpha}{3}\right) \frac{d}{d\tau} \int_{0}^{\tau} \mathcal{O}\left(\frac{v}{\tau}\right) d\tau = U(\tau)$$
 is the soliton

velocity. Now, by substituting this solution (Eq. (39)) into the energy conservation equation (Eq. (37)), we obtain the following expressions of energy  $(\mathcal{E})$ , amplitude  $(\emptyset)$ , velocity (U) and spatial width (L) of the soliton, respectively:

$$\mathcal{E}(\tau) = \mathcal{E}(0) \exp(-\nu \tau),$$
 <sup>(40)</sup>

$$\Psi(\tau) = \Psi(0) \exp\left(-\frac{2\nu}{3}\tau\right), \qquad (41)$$

$$U(\tau) = \frac{\alpha \Psi(0)}{3} \exp\left(-\frac{2\nu}{3}\tau\right), \qquad (42)$$

$$L(\tau) = \sqrt{\frac{12\beta}{\alpha\Psi(0)}} \exp\left(\frac{\nu}{3}\tau\right). \tag{43}$$

where  $\mathcal{E}(0)$  and  $\mathcal{O}(0)$  are the initial soliton energy and amplitude. The above soliton solution is not exact. It is an approximated leading order soliton solution, even though it is well accepted for dissipative perturbation. The contribution made by the higher order term is only the correction to this solution though the change in amplitude, velocity, and width remain same as obtained in the leading order approximation(Newell 1985)It is clear from the above solution that the ion-neutral collisional effect causes the soliton energy  $\mathcal{E}$ , soliton amplitude  $\emptyset$  and soliton velocity U to decay exponentially with increasing time  $(\tau)$  according to equations (40), (41) and (42), respectively, whereas the soliton width L increases with increasing time ( $\tau$ ) according to equation (43). The propagates finite distance  $L_d = \frac{\emptyset(0)}{2\nu}$  before dying out at  $\tau \rightarrow \infty$ . The solution (Eq. (39)) has been plotted in Figures3 and 4. In the presence of collision, Figure3(b) shows the wave amplitude decreases exponentially with the increase of time. Figure 4(a) shows that width of the soliton is proportional to the dispersion parameter D. Amplitude of the wave decreases exponentially with the increase of  $\nu$  shown in Figure4(b).

## 6. Numerical Solutions

In the process of solving the damped nonlinear KdV equation (35) numerically, we have taken the help of the MATHEMATICA based finite difference scheme. Since the KdV equation (35) in the absence of collisions possesses a single soliton solution, for time-dependent numerical simulation of equation (35) in presence of collision, we use the single soliton solution as the initial wave profile:

$$\psi(\xi,0) = \left(\frac{3U}{\alpha}\right) \operatorname{sech}^2\left(\sqrt{\frac{U}{4\beta}}\xi\right), \xi \in [-L,L],$$

where  $U = \frac{\alpha \emptyset(0)}{3}$  is the soliton velocity and L

is the spatial length. The boundary conditions

are 
$$\psi(\pm L, \tau) = \left(\frac{3U}{\alpha}\right) \operatorname{sech}^2\left(\pm\sqrt{\frac{U}{4\beta}}L\right)$$
 and

 $\psi_{\xi}(-L,\tau) = 0 = \psi_{\xi}(L,\tau)$ . To obtain the precise results in computation, we have taken the value of the following parameters as the acoustic to Alfvén velocity ratio M = 0.94, spatial length L = 20, dispersion parameter D = 1.0 and normalized soliton velocity U = 0.6. The time-dependent numerical simulations of the KdV equation (35) is plotted in Figures5 and 6. Figure 5(a) shows that the amplitude and width of the magnetosonic solitary wave decrease and increase exponentially, respectively, with the increase of normalized time for normalized ion-neutral collisional frequency v = 0.1 which is qualitatively same as corresponding analytical solution. Similarly, next Figure (b) shows the decreasing amplitude with respect to increasing normalized ion-neutral collisional frequency  $\nu$  for the normalized time  $\tau = 5$ which is also qualitatively same as corresponding analytical solution. The last figure (Figure 6) indicates the diminishing amplitude of the magnetosonic wave with the increase of time  $\tau$  in three dimensions. Therefore, the numerical simulation of the KdV equation (35) and the time-dependent analytical solutions exhibit the same nature of the propagated magnetosonic wave.



Figure 3: (a) Plot of analytical solution Eq. (38) in absence of collision ( $\nu = 0$ ) for different normalized time  $\tau$ . (b) Plot of analytical solution Eq. (39) in presence of collision with  $\nu = 0.1$  for different normalized time  $\tau$ . Other plasma parameters are M=0.94, U=0.6, D=1.0.



**Figure 4:** Plot of analytical solution Eq. (39) (a) for different dispersion parameter D with  $\nu = 0.1$  and  $\tau = 0$ . (b) for different  $\nu$  with D=1.0 and  $\tau = 5$ . Other plasma parameters are M=0.94, U=0.6.



Figure 5: Numerical solution of damped KdV Eq. (35) (a) for different normalized time  $\tau$  and  $\nu = 0.1$ ; (b) for different  $\nu$  and  $\tau = 5$ . Other plasma parameters are M=0.94, U=0.6 and D=1.



Figure 6: 3D plot of damped KdV Eq. (35) for plasma parameters M=0.94, U=0.6, D=1 and  $\nu = "$ .

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### 7. Conclusions

This paper dealt with the effect of ion-neutral collisions on the propagation of nonlinear magnetosonic waves in magnetized pair-ion plasmas consisting of positive and negative fullerene ions  $(C_{60}^{\pm})$  of equal mass. The temperatures of positive and negative ions are slightly different as the charging processes of the ions are different. To incorporate the collision in the system, we have assumed the ion-neutral collision frequency is much smaller than the cyclotron frequency of ions. The external magnetic field is applied in the  $e_z$  direction. We have adopted the Reductive Perturbation Technique (RPT), taking a two-fluid model for positive and negative ions. The nonlinear magnetosonic wave is governed by the Korteweg -de Vries equation (KdV) with a linear damping term. Both analytical and numerical analysis reveal the existence of weakly dissipative magnetosonic solitary waves. In the presence of collision, soliton energy, amplitude, and velocity decrease exponentially, whereas the soliton width increases exponentially with time.

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# 74. Star formation in presence of magnetic field: Exploring a 2D dynamical system perspective

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#### Abstract

A 2D dynamic model is utilized to investigate Star formation in filamentary molecular clouds amidst magnetic fields. The study reveals that the emergence of field stars is possible under both weak and strong magnetic fields due to the presence of low-density structures. An intermediate-density structure in the presence of a moderate magnetic field can form a combination of binary stars and field stars, whereas, in a very high dense filamentary molecular clouds, a low magnetic field may help to form binary stars or stellar associations.

Keywords: Molecular cloud, magnetic field, star formation.

### 1. Introduction

The interstellar medium (ISM) displays a predominantly filamentary structure across various scales, as evidenced by studies such as Schneider & Elmegreen 1979, Hartmann 2002, Myers 2009, and Flagey et al. 2009. These self-gravitating filaments serve as the birthplaces of stars. Star-forming molecular clouds are threaded by magnetic fields, which certainly influence cloud morphology and evolution (Krumholz & Federrath 2019).

This study delves into the evolution of a collection of nonlinear dynamical equations, derived from an extended form of the double-well potential. We explore diverse physical scenarios to unravel the mechanisms giving birth to field, binary, and multiple star systems in a magnetized molecular clouds.

In Section 2, the mathematical model is expounded upon. Following this, Section 3 outlines and deliberates upon the initial parameter values. Section 4 encompasses the presentation and discourse of results, while the concluding remarks can be found in Section 5. Additional mathematical derivations are provided in Appendix A.

### 2. Mathematical Model

In this work, we have studied the dynamical evolution of the filamentary molecular cloud (hereafter FMC) in the presence of the magnetic field. Mondal et al. (2021) studied the evolution of rotating FMC. For this purpose, they considered double-well potential (hereafter DWP), which has similar density structures to FMC. They introduced the following generalized DWP (Eq.1) in a two-dimensional system and compared the similarity between DWP and FMC.

$$V(X, Y, Z_x^2, Z_y^2) = -Z_x^2 X^2 - Z_y^2 Y^2 + \lambda (a_{xx} X^4 + 2a_{xy} X^2 Y^2 + a_{yy} Y^4)$$

Details of these parameters  $Z_x^2, Z_y^2, a_{xx}, a_{xy}, a_{yy}$ , and  $\lambda$ , and their significance can be found in Mondal et al. (2021). Here, we further study in presence of a constant magnetic field. In a spiral galaxy, the magnetic field is directed along the direction of spiral arms. Thus, it has no component along z-direction, i.e.,  $\vec{B} = (B_x, B_y, 0)$ , and the corresponding magnetic force components along x and y directions are  $-\frac{B^2 x}{x^2 + y^2}$  and  $-\frac{B^2 y}{x^2 + y^2}$  respectively. So in the presence of a constant magnetic field strength B along the spiral arm, the social equations of motion for

spiral arm, the scaled equations, of motion for general DWP are,

$$x = 2Z_x^2 x - \lambda \left( 4a_{xx}x^3 + 4a_{xy}xy^2 \right) - \frac{1}{\rho} \frac{B^2 x}{x^2 + y^2},$$
  
$$y = 2Z_y^2 y - \lambda \left( 4a_{yy}y^3 + 4a_{xy}x^2y \right) - \frac{1}{\rho} \frac{B^2 y}{x^2 + y^2},$$

where  $\rho$  is the density of the molecular clouds.

Here, we have made dimensionless (See Appendix A) X, Y, and T by  $X = x \times 10^{17}$  cm,  $Y = y \times 10^{17}$  cm, and  $T = t \times 10^{13}$  s for observational compatibility.

For stability analysis, we transformed the aforementioned second-order differential equations into a system of first-order differential equations. The number of solutions or fixed points is 16 of which 8 of them can be written as

(i) 
$$\left\{ x = 0, y = \pm \frac{\sqrt{\rho Z_y^2 \pm \sqrt{\left(\rho Z_y^2\right)^2 - 4\lambda\rho B^2 a_{yy}}}}{2\sqrt{\rho\lambda a_{yy}}} \right\},$$
  
(ii) 
$$\left\{ x = \pm \frac{\sqrt{\rho Z_x^2 \pm \sqrt{\left(\rho Z_x^2\right)^2 - 4\lambda\rho B^2 a_{xx}}}}{2\sqrt{\rho\lambda a_{xx}}}, y = 0 \right\},$$

The mathematical expression for the remaining stationary points are very large to be quoted. We have studied the stability of this system of stationary points in Table 1 by considering suitable arbitrary values of the parameters  $\lambda$ ,  $a_{xx}$ ,  $a_{xy}$ ,  $a_{yy}$ ,  $Z_x^2$ and  $Z_y^2$ , for which the eigenvalues are real neg-

and  $Z_y^2$ , for which the eigenvalues are real negative or their real parts are close to zeros as found through numerical computations. The eigenvalues of the corresponding Jacobian matrix can be

expressed as 
$$\pm \frac{\sqrt{(P_2 + R_2) \pm \sqrt{(P_2 - R_2)^2 + 4Q_2^2}}}{\sqrt{2}}$$

where, 
$$P_2 = 2Z_x^2 - 12\lambda a_{xx}x^2 - 4\lambda a_{xy}y^2 + \frac{B^2(x^2 - y^2)}{\rho(x^2 + y^2)^2}$$
,  
 $Q_2 = -8\lambda a_{xy}xy + \frac{2B^2xy}{\rho(x^2 + y^2)^2}$  and  
 $R_2 = 2Z_y^2 - 12\lambda a_{yy}y^2 - 4\lambda a_{xy}x^2 - \frac{B^2(x^2 - y^2)}{\rho(x^2 + y^2)^2}$ 

• --- <sup>2</sup>

One sufficient condition for which a stationary point becomes a stable center is  $P_2R_2 > Q_2^2$ .

# 3. Initial Values of the Parameters

Several researchers showed that the magnetic field in the molecular clouds is of the order  $\mu$ G (Khesali et al. 2014). The range of mean magnetic field strength is from  $1.4 \mu G$  to  $14 \mu G$ (Ostriker et al. 2001) in giant molecular cloud (GMC). Thus, we have considered the range of B from  $1.4\mu G$  to  $14\mu G$ . Initial number density of Molecular cloud is  $\sim 10^4$  cm<sup>-3</sup> to  $10^5$  cm<sup>-3</sup> (Herbst & Klemperer (1973); Goldsmith & Langer (1978); Bally et al. (1987, 1988); Caselli et al., 1999), and the peak density is  $\sim 10^5$  cm<sup>-3</sup> (Myers 2017). However, some authors showed the mean cloud density  $n_{H_2}$  in clumps is  $10^3 \text{ cm}^{-3}$  (Gammie & Ostriker, 1996; Ostriker et al. 1999), and it is typically from ~ 25 cm<sup>-3</sup> to 100 cm<sup>-3</sup> in cloud complexes. Throughout our present work, we have considered the number density in Molecular clouds as  $10^4$  cm<sup>-3</sup> i.e.  $\rho = 1.67 \times 10^{-20} \text{ g cm}^{-3}$ .

### 4 Results and Discussion

In this study, we have developed a synthetic model to investigate the potential of a Double-Well Potential (DWP) to facilitate the formation of field stars, binary pairs, or stellar associations within Filamentary Molecular Clouds (FMCs). The density patterns associated with a DWP can exhibit resemblances to those observed in FMCs (Mondal et al. 2021), which are often the aftermath of intense shock waves influenced by helical magnetic fields (McKee et al., 1993; Fiege & Pudritz, 2000; Heiles et al., 1993; Schleuning 1998; Pudritz & Kevlahan 2013).

Table 1.	The number	of stationary	points and	l stable	centers i	for variou	is self-gravit	tating magn	netized
filamenta	ary MC types.	•							

λ	<i>a</i> <sub>xx</sub>	$a_{xy}$	<i>a<sub>yy</sub></i>	$Z_x^2$	$Z_y^2$	$B$ $(\mu G)$	No. of stationary points	No. of stable centers (X,Y) (pc,pc)
0.25 <i>e</i> -5	1	1	2	0.05	-0.05	10	4	2 (±3.135,0)
0.25e-5	1	1	2	0.05	-0.05	14	4	2 (±3.012,0)
0.25 <i>e</i> -5	1	1	2	0.05	-0.05	5	4	2 (±3.215,0)
0.25e-4	1	1	2	0.05	-0.05	10	0	0
0.25e-4	1	1	2	0.05	-0.05	6	4	2 (±0.8484,0)
0.25 <i>e</i> -5	1	1	2	0.5	-0.005	10	4	2 (±32.404,0)
0.25 <i>e</i> -5	1	1	2	0.6	0.5	10	4	2 (±11.223,0)
0.25 <i>e</i> – 5	1	1	2	0.5	0.6	10	12	4 (±9.162,±4.583)
0.25e-5	1	1	2	1	1	10	8	0
0.25e-4	1	1	2	0.05e+1	-0.05 <i>e</i> +1	6	4	2 (±3.237,0)
0.25 <i>e</i> -4	1	1	2	0.05e+1	-0.05e+1	1.4	4	2 (±10.247,0)
0.25e-5	1000	1000	2000	0.05	-0.05	10	0	0
0.25e-5	1000	1000	2000	0.05	-0.05	1.4	0	0
1	1e-7	1e-7	2e-7	1e-2	1.96e – 2	10	8	2 (0,±7.057)

Table 1: (Continued)

1	1e-7	1 <i>e</i> -7	2 <i>e</i> -7	1e-2	1.96e – 2	5	12	4 (±1.141,±7.099)
1	1e-7	1e-7	2e-7	1e-2	1.96e – 2	14	8	$ \begin{array}{c} 4 \\ (0, \pm 6.935) \end{array} $
2	1e-7	1e-7	2e-7	1e-2	1.96e – 2	10	8	$\begin{array}{c} 2\\ (0,\pm 4.900) \end{array}$
1	1e-7	1e-7	2e-7	1e-1	1.96e-1	10	12	4 (±4.548,±22.450)
1	1 <i>e</i> -6	1e-6	2e-6	1e-2	1.96e-2	10	0	0
1	1e-6	1e-6	2 <i>e</i> -6	1e-2	1.96e-2	5	8	2 (0,±2.267)
1	1e-4	1e-4	2e - 4	1e-2	1.96e – 2	10	0	0
1	1e-4	1e-4	2e - 4	1e-2	1.96e-2	5	0	0
1e-2	1	1	2	1	1.96	10	0	0
1e-2	1	1	2	1	1.96	14	0	0
1e-2	1	1	2	1	1.96	1.4	12	4 (±0.0382,±0.2242
1e-2	1	1	2	1	1.96	5	8	$\begin{array}{c} 2 \\ (0, \pm 0.2168) \end{array}$
1e-3	1	1	2	1	1.96	10	8	$\begin{array}{c} 2\\ (0,\pm 0.7057) \end{array}$
1e-3	1	1	2	1	1.96	1.4	12	4 (±0.1428,±0.7099
1e-3	1	1	2	1e-2	1.96e-2	10	0	0
1e-3	1	1	2	1e-2	1.96e-2	1.4	0	0
1e-3	10	10	20	1	1.96	10	0	0
1e-3	100	100	200	1	1.96	10	0	0
1e-3	100	100	200	1	1.96	1.4	8	2 $(0,\pm 0.0693)$
0.25	1e-7	0	0	0.5 <i>e</i> -2	-0.5e-2	10	4	2 (±9.912,0)

0.25	1e-7	0	0	0.5 <i>e</i> -2	-0.5e-2	5	4	2 (±10.167,0)
0.25	1e-7	0	0	0.5 <i>e</i> -2	-0.5e-2	14	4	2 (±9.524,0)
0.25e-1	ü –	0	0	0.5e-2	-0.5e-2	10	4	(±32.301,0)
0.25e+1	1e-7	0	0	0.5e-2	-0.5e-2	10	0	0
0.25	1e-7	0	0	0.5	-0.5	10	4	2
0.25	ü –	1	0	0.5e-2	-0.5e-2	10	0	0

Table 1: (Continued)



**Figure 1.** Phase space for the gravitational potential in the presence of a constant magnetic field  $B = 10 \mu G$  for  $\lambda = 0.25 \times 10^{-5}$ ,  $a_{xx} = 1$ ,  $a_{xy} = 1$ ,  $a_{yy} = 2$ ,  $Z_x^2 0.05$ ,  $Z_y^2 = -0.05$ . Stable stationary points at the center are denoted by green dots, while specific solutions originating from positions indicated by red stars are represented by blue curves.

Our investigation focuses on the presence of stable stationary points in the DWP model, considering a range of parameter values such as  $Z_x, Z_y, a_{xx}, a_{xy}, a_{yy}$ , and  $\lambda$ , in conjunction with various magnetic field strengths (B). The outcomes are presented in Table 1 and Figure 1. Drawing from Jiménez-Esteban et al.'s (2019) analysis of 3741 commoving binary and multiple stellar systems in the Gaia DR2 catalogue, it was revealed that these candidate systems exhibit separations ranging approximately from 400 to 500,000 AU, equivalent to 0.00194 pc to 2.45 pc. Hence in the present

study we have considered the maximum distance between two binary stars is 2.45pc. Typically, magnetic field in giant spiral galaxies is along the spiral arms (Beck 2015). Therefore, we have considered a constant magnetic field along cross-radial direction. Table 1 compiles the analysis results in the presence of magnetic field. We observe the following facts. When  $\lambda$  is very small (~10<sup>-5</sup>) and DWP is asymmetric (here,  $a_{xx} = a_{xy} = 1, a_{yy} = 2, Z_x^2 = 0.05$  and  $Z_y^2 = -0.05$ ) then field stars formation is very likely. These values of the parameters indicate a small depth of the DWP, i.e., the density distribution of the DWP is lighter, which corresponds to more scattered FMC. In these clouds, a higher magnetic field in a self-gravitating filamentary molecular cloud only reduces the distance between two stable points situated along the horizontal axis. Thus, when B increases the distance between stable points decreases. When the magnetic field is large (~ $10\mu G$ ), then for a less deep DWP (i.e. all  $\lambda, a_{xx}, a_{xy}, a_{yy}$  are small) no stars will form, i.e., there are no stable centers). Few field stars may form (i.e., one or two or more stationary points exist with separation of more than 2.5pc) in a large magnetic field with comparatively shallower DWP (here  $\lambda$  should be very high,  $\sim 1$ ).

When  $\lambda \sim 10^{-5}$  and  $a_{xx} = a_{xy} = 1000, a_{yy} = 2000, Z_x^2 = 0.05$  and  $Z_y^2 = -0.05$ , then no stable stationary point is found. Since  $\lambda$  is low and  $a_{xx}, a_{xy}$  and  $a_{yy}$  are high, their combined effect indicate a moderate-ly high depth of the DWP i.e., moderately high dense FMC.

When  $\lambda \sim 10^{-2}$  and  $a_{xx} = a_{xy} = 1, a_{yy} = 2, Z_x^2 = 1$  and  $Z_y^2 = 1.96$ , then in presence of strong magnetic field ( $\sim 10 \mu G$  or more) no stars is formed, whereas, in presence of low magnetic field ( $\sim 1.4 \mu G$ ) multiple stable stationary points occur. In the presence of moderate magnetic field ( $\sim 5\mu G$ ), binary pair forms i.e., it helps to acquire material to accumulate at two close centres leading to formation of binary stars. Since for higher values of the parameters  $a_{xx}, a_{xy}$ , and  $a_{yy}$ , the corresponding surface density of the FMC is high, so in high dense FMC, effect of magnetic field acts against star formation, whereas, a low magnetic field helps to form binary star formation or the formation of stellar association.

When  $\lambda \sim 1$  and  $a_{xx} = a_{xy} = 10^{-7}, a_{yy} = 2 \times 10^{-7}, Z_x^2 = 10^{-2}$  and  $Z_y^2 = 1.96 \times 1.96 \times 10^{-2}$ , in presence of moderate magnetic field (~ 5µG), a combination of binary stars and field stars may form. For these

binary stars and field stars may form. For these parameters, the density of the FMC is moderate. In the presence of a strong magnetic field isolated stars are formed.

# 5. Conclusions

This study employs a synthetic model that leverages the double well potential concept to forecast various star formation scenarios within different categories of Filamentary Molecular Clouds (FMCs) under the influence of a magnetic field

- i. When the depth of the potential is low, i.e., for lesser-dense FMC most of the stars are formed as field stars in the presence of weak as well as strong magnetic fields. The effect of magnetic field on the number of stars is less
- When the filamentary MC have an intermediate density then in presence of moderate magnetic field a combination of binary stars and field stars form, whereas, in presence of low magnetic field stellar association may form. The presence of very strong magnetic field stops star formation.
- iii. For moderately high or very high dense FMC, a low magnetic field may help to form binary stars or stellar associations. But, a strong magnetic field strongly acts against star formation, and no star forms.

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# **Appendix: Scalling**

$$X = 2Z_x^2 X - 4\lambda \left( a_{xx} X^3 + a_{xy} X Y^2 \right) - \frac{1}{\rho} \frac{B^2 X}{X^2 + Y^2} + {}^2 X + \dot{Y}.$$
 Let us put,  

$$X = x \times 10^{17} \text{ cm}, Y = y \times 10^{17} \text{ cm}, \text{ and}$$

$$T = t \times 10^{13} \text{ s}.$$
 Then the above equation

 $T = t \times 10^{13}$  s. Then the above equation reduces to

$$\frac{10^{17}}{10^{26}}x = 2Z_x^2 \left(x \times 10^{17}\right) - 4\lambda \left(a_{xx}x^3 + a_{xy}xy^2\right) \times 10^{51} - \frac{1}{\rho}\frac{B^2 x}{x^2 + y^2} \frac{1}{10^{17}} + \dot{U}^2 x \times 10^{17} + 2\dot{U}\dot{y} \times \frac{10^{17}}{10^{13}}.$$
Or,  $x = 2\left(Z_x^2 \times 10^{26}\right)x - 4\left(\lambda \times 10^{60}\right)$ 
 $\left(a_{xx}x^3 + 4a_{xy}xy^2\right) - \frac{1}{\rho}\frac{B^2 x}{x^2 + y^2} 10^{-8} + \dot{U}^2 x \times 10^{26} + 2\dot{U}\dot{y} \times 10^{13}.$ 
Or,  $x = 2Z_x'^2 x - 4\lambda' \left(a_{xx}x^3 + a_{xy}xy^2\right)$ 
 $-\left(\frac{B^2 \times 10^{-8}}{\rho}\right)\frac{x}{x^2 + y^2} + (\dot{U} \times 10^{13})\dot{y}.$ 

Where  $Z_x^{'2} = Z_x^2 \times 10^{26}$  and  $\lambda' = \lambda \times 10^{60}$ . Now let **a**, **b** are two constants such that their ranges are from 1.4 to 14, and from 0.01 to 3 multiplied by 0.3241, respectively. So, we can write  $B = a \times 10^{-6} G$ , and  $\dot{\mathbf{U}} = b \times 10^{-13} s^{-1}$ . Also  $\rho = 1.67 \times 10^{-20}$  gcm<sup>-3</sup>. Therefore,  $\frac{B^2}{\rho} \approx 10^8$ ,  $\dot{\mathbf{U}}^2 \approx 10^{-26}$ , and  $\dot{\mathbf{U}} = 10^{-13}$ . Thus, the equation of motion along the **x** – **axis** in reduced form is  $x = 2Z_x'^2 x - 4\lambda' (a_{xx}x^3 + a_{xy}xy^2)$ 

$$-\frac{1}{\rho'}\frac{B'^2x}{x^2+y^2} + \frac{y^2}{x^2+y^2} + \frac{y}{y}$$

Where  $\mathbf{B}' = \mathbf{a}, \rho' = 1.67, \dot{\mathbf{U}}' = b$ . Since  $Z_x^{'2}$ and  $\lambda'$  are arbitrary constants, the form of this reduce equation is the same with the original equation before scaling. For the equation of motion along the axis, after scaling, we get the same type of equation as the original equation with  $\mathbf{B}' = \mathbf{a}, \rho' = 1.67, \dot{\mathbf{U}}' = b$ .

# 75. Impact of nonlinear dispersion and velocity in the aquifer close to the large water-bodies: Three-dimensional time-fractional model

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### Abstract

In this study, authors explore the impact of nonlinear dispersion and velocity in aquifer aquitard system due to presence of large water bodies. A finite aquifer with heterogeneous soil medium has been considered. Integer order advection dispersion Eq. mostly considered to model the contaminant transport in porous media. Due to the presence of large water bodies a direct impact in contaminant transport will be there. To model the impact, three-dimensional time-fractional advection dispersion Eq. (TFADE) has been considered to formulate the fluid flow through heterogeneous soil medium mathematically. The boundaries of the aquifer have improper formation often. To assign the boundary condition for an aquifer is quite difficult as it does not follow any proper mathematical figures/ objects but in the other hand one can easily get the initial condition for the aquifer by laboratory testing of the aquifer water. To overcome this difficulty present problem uses only initial condition to predict the contaminant transport phenomena in the aquifer system. Without loss of generality it is considered that initially the aquifer is contaminant free. Homotopy perturbation method (HPM) has been implemented to solve the TFADE semi-analytically. MatLab software has been used for graphical representation of the solution of the problem.

Keywords: Heterogeneous aquifer, Time-fractional, Nonlinear velocity and dispersion, HPM.

# 1. Introduction

Groundwater is one of the most important sources of fresh water in rural India as well as world. Major part of the groundwater is used for cultivation and drinking in rural areas. From the last few decades various groundwater contamination problems were taken into consideration to model the real life situation and to get rid of this problem. Advection dispersion Eq. (ADE) was used to formulate the groundwater contamination problems mathematically. Various solution of ADE to model the transport through porous media with different source type, boundary and initial conditions with heterogeneity, anisotropy and dispersivity was solved with different solution techniques (Chen & Liu 2011; Sander & Braddock 2004; Singh et al. 2008). The ADE is the fundamental study of many other branches of hydrology. The ADE can be applied to model solute transport in streams and unsaturated soil. Solution methods are either analytical or numerical even in some case it is stochastic.

Fractional derivatives were introduced earlier but recently the fractional derivatives have been used to model the physical systems. Fractional derivatives are usedmodelling the groundwater contamination problem in heterogeneous medium. Various methodologies like finite difference, finite element, series, homotopy perturbation and homotopy analysis have been used to solve the FADE. Benson et al. (2000) solved FADE by Green function method. Time and distance independent dispersion parameters were considered, where fractional derivative represent the scaling behaviour of Levy motion. Berkowitz et al. (2002) used FADE to model the conservative chemical transport in heterogeneous geological formations. Schumer et al. (2003a) studied multi-scaling FADE to model the solute transport mechanism in irregular non-continuum fracture networks, where fractional derivative of matrix order represented the super-Fician dispersion and green function method along with Fourier transform was used to solve this problem. Schumer et al. (2003b) used time fractional derivative to represent the waiting time in immobile zone of a fractal mobile/immobile solute transport modelling, solved the boundary value problem with the help of integral transform method. Meerschaert and Tadjeran (2004) presented a one-dimensional FADE with variable coefficient to model the transportation of passive tracers in porous media and solved the FADE using finite difference approximation. Deng et al. (2004) explored two different type numerical schemes to explore the one-dimension space-fractional ADE (SFADE) and conclude that "F.3 central scheme" produce less error and more stable solution than "1.3 Backward Scheme". Zhang et al. (2005) implemented finite volume approach to solved onedimension fractional advection-dispersion Eq.s in which only dispersion term is fractional order and compared the numerical solution with analytical solution for accuracy. Deng et al. (2006) estimated parameter of non-Fickian dispersion model for rivers with first order reaction term experimentally and found that the fractional dispersion operator parameter F is varies from 1.4 to 2.0. Zhang et al. (2007) explored the three models of one-dimension homogeneous SFADE where velocity and dispersion coefficient are function of space using the generalized mass balance law. Wheatcraft and Meerschaert (2008) used fractional-order derivative to develop the traditional mass conservation Eq.

and concluded that "fractional-order conservation of mass Eq. will be exact when the fractional order of differentiation matches the flux power-law". Murio (2008) modelled the long memory transport mechanism with inconsistent diffusion rate by the classical Brownian motion and solved the time fractional diffusion Eq. semi-analytically with the help of finite element method. Huang et al. (2009) solved onedimension FADE using finite element method approach along with caputo definition of fractional order derivative and verified the accuracy and stability of the finite element solution against the analytical solution. Chakraborty et al. (2009) developed one-dimension SFADE and particle tracing approach to estimate parameters. Shen and Phanikumar (2009) discussed the three different type numerical schemes to solve the one-dimension SFADE and concluded that fully-implicit Grünwald-Letnikov method with Richardson extrapolation gives the most significant result among them. Li et al. (2009) solved time-fractional diffusion Eq. with a moving boundary condition by extended HPM and showed that in most of the practical application the approximate solution was sufficiently accurate. Aghili and Ansari (2012) derived an inversion formula of " $L_2$  transformation" and apply this transformation to fractional partial differential Eq.. Khader et al. (2013) used "Chebyshev pseudo-spectral method" to derive the solution of fractional integro-differential Eq.s. Sun et al. (2013) also solved time-fractional diffusion Eq.s using the finite element method. To solve the fractional integro-differential Eq. with caputo sense fractional derivative numerically a spectral Jacobi-collocation method proposed by Ma and Huang (2014). Singh et al. (2017) derived the solution for one dimensional TFADE in the presence of only initial condition using homotopy analysis method and compared the solution with finite element method when the fractional order becomes one. Pandey et al. (2020) modelled the solute transport in heterogeneous aquifer by one-dimensional SFADE and presented different contaminant concentration distribution profile for different type of dispersion and velocity.

In this present problem, authors explore the solute transport in heterogeneous aquifer and the impact of non linear dispersion and velocity in the aquifer nearer to some water body. Since the aquifer is situated near a water body so huge water pressure will be there and also the velocity and dispersion varies according to the season throughout the year, along with different dispersion and velocity in different place because of heterogeneity of soil/medium in aquifer, so we consider nonlinear (space- time dependent) dispersion and velocity.A three dimensional finite heterogeneous aquifer is considered to model the problem.Fractional order ADE was solved by many researchers but impact of non-linear velocity and dispersion due to large water bodies near the aquifer system has not been considered as far our knowledge. Fractional order derivatives preserve the memory and help to realize the change in the system with time the groundwater flow mechanism has also been observed from the present time fractional model. So, Three-dimensional time-fractional advection dispersion Eq. (TFADE) has been considered to understand the solute transport throughout the aquifer. It is very difficult to assign the boundary condition for heterogeneous aquifer as it does not follow any proper formation but in the other hand one can easily get the initial condition for the aquifer by laboratory testing of the aquifer water. So in this present problem only initial condition is considered. According to our consideration the aquifer was initially contamination free. HPM is used to solve this highly non-linear time-fractional advection-dispersion problem. From the solution of three-dimensional TFADE one can easily derived the solution for two-and one-dimensional TFADE and general non-linear ADE.

# 2. Mathematical Formulation of the Problem

Here we considered the solute transport problem in heterogeneous porous media (heterogeneous aquifer). In reality, it is seen that the source of the groundwater contamination are different in different time as well as different place, so we consider space-time dependent source. A finite aquifer with soil mixed medium considered to model the problem mathematically. Let  $C(x, y, z, t)[ML^{-3}]$  be the contaminant concentration at a point (x, y, z) and at a time t. Then the TFADE with source can be written as

$$\frac{\partial^{\alpha} C}{\partial t^{\alpha}} = \frac{\partial \left( D_x(x,t) \frac{\partial C}{\partial x} \right)}{\partial x} + \frac{\partial \left( D_y(y,t) \frac{\partial C}{\partial x} \right)}{\partial y} + \frac{\partial \left( D_z(z,t) \frac{\partial C}{\partial x} \right)}{\partial z} - \frac{\partial \left( u_x(x,t)C \right)}{\partial x} - \frac{\partial \left( u_y(y,t)C \right)}{\partial y} - \frac{\partial \left( u_z(z,t)C \right)}{\partial z} + F\left( x,y,z,t \right)$$
(1)

W h e r e  $D_x(x,t)[L^2T^{-1}]$ ,  $D_y(y,t)[L^2T^{-1}]$ ,  $D_z(z,t)[L^2T^{-1}]$ , and  $u_x(x,t)[LT^{-1}]$ ,  $u_y(y,t)[LT^{-1}]$ ,  $u_z(z,t)[LT^{-1}]$  are the space-time dependent dispersion and velocity components along x , y and z axes respectively, F(x,y,z,t) is the space-time dependent source. We consider contamination free aquifer initially.

Therefore, the initial condition can be written as

$$C(x, y, z, t) = 0; \ t = 0, x \ge 0, y \ge 0, z \ge 0$$
(2)

### 3. HPM Methodology

The TFADE can be written in the form as:

 $D_{*t}^{\alpha}C = F^{*}(C, C_{x}, C_{xx}C_{y}, C_{yy}, C_{z}, C_{zz}), t > 0$ (3) Where  $F^{*}$  and are non-linear function and differential operator respectively, given by:  $D_{*t}^{\alpha}f = I^{m-\alpha}D^{m}f$  (4)

Here,  $D^m$  is the usual integer differential operator of order m,  $m-1 < \alpha \le m$ , and  $I^{\alpha}$  is the Riemann-Liouville integral operator of order  $\alpha > 0$ , defined as:

$$I^{\alpha}f = \frac{1}{\Gamma(\xi)} \int_{0}^{x} (x-t)^{\alpha-1} f(t) dt, \quad x > 0$$
 (5)

Where  $\mu$  is the parameter, and  $I^{\alpha}$  satisfies the properties for  $f \in C_{\xi}, \xi > -1, \alpha > 0, \beta > 0$  given bellow.

$$I^{\alpha}t^{\gamma} = \frac{\Gamma(\gamma+1)}{\Gamma(\alpha+\gamma+1)}t^{\alpha+\gamma}$$
(6)

$$I^{\alpha}I^{\beta}f(t) = I^{\alpha+\beta}f(t)$$
(7)

$$I^{\alpha}I^{\beta}f(t) = I^{\beta}I^{\alpha}f(t)$$
(8)

The TFADE (1) can be written in a general form (Momani & Odibat 2007; Singh et al. 2017) as follows

$$D_{*_{t}}^{a}C(x, y, z, t) = L(C, C_{x}, C_{xx}, C_{y}, C_{yy}, C_{z}, C_{zz}) + N(C, C_{x}, C_{xx}, C_{y}, C_{yy}, C_{z}, C_{zz}) + F(x, y, z, t) \qquad t > 0,$$
(9)

Where *L* is linear and *N* is non-linear operator that may contain other fractional order derivative less than  $\alpha$ , *F* is a known source function, and  $D_*^{\alpha}$ ,  $m-1 < \alpha \le m$ , is the Caputo sense fractional derivative of order  $\alpha$ , where the initial condition is given as follows:

$$C^{k}(x, y, z, 0) = c_{k}(x, y, z), \qquad k = 0, 1, 2, ..., m - 1$$
(10)

Now, we establish the homotopy for Eq. (9) (Momani & Odibat 2007; Singh et al. 2017) as follows:

$$\frac{\partial C^{m}}{\partial t^{m}} - F(x, y, z, t) = p \begin{bmatrix} \frac{\partial C^{m}}{\partial t^{m}} + L(C, C_{x}, C_{xx}, C_{y}, C_{yy}, C_{z}, C_{zz}) \\ + N(C, C_{x}, C_{xx}, C_{y}, C_{yy}, C_{z}, C_{zz}) \\ - D^{\alpha}_{\epsilon_{t}}C(x, y, z, t) \end{bmatrix}$$
(11)

Where  $p \in [0,1]$  is the homotopy parameter, p is also called the embedding parameter.

If p = 0, then Eq. (11) becomes linear:

$$\frac{\partial C^m}{\partial t^m} = F(x, y, z, t), \tag{12}$$

Solution of Eq. 12 gives the zeroth order approximation.

When p = 1, Eq. 11 is identical with Eq. 9, the solution of the Eq. 11 is the exact solution. Therefore, the zeroth order approximation converges to exact solution according to the value of *p* converges from zero to unity. Then, using this deformation technique we can find the exact solution of the Eq. 11. The power series able to write the power series solution in terms of *p* as solution of Eq. 11 can be written in the power of <sup>*p*</sup> as:

$$C(x, y, z, t) = C_0(x, y, z, t) + pC_1(x, y, z, t) + p^2C_2(x, y, z, t) + p^3C_3(x, y, z, t) + \dots$$
(13)

All other higher order approximation  $C_n(x, y, z, t)$  n = 1, 2, 3.... obtained by Substituting Eq. 13 in Eq. 11 and equating terms of equal powers of P,  $C_n(x, y, z, t)$  is the nth order coefficient of the power series generated by P. As P tends to unity, the solution becomes

$$C(x, y, z, t) = \sum_{n=0}^{\infty} C_n(x, y, z, t)$$
(14)

Only a few terms of  $C_n(x, y, z, t)$  are needed to write Eq. 14 as a truncated series:

$$C_N(x, y, z, t) = \sum_{n=0}^{N-1} C_n(x, y, z, t)$$
(15)

Thus,  $C(x, y, z, t) \approx C_N(x, y, z, t)$ 

# 4. Approximate Analytical Solution

HPM methodology earlier discussed by (Momani & Odibat 2007; Singh et al. 2017) we can write Eq. 1 using the methodology as follows:

$$\frac{\partial C}{\partial t} - F(x, y, z, t) = p \begin{pmatrix} \frac{\partial C}{\partial t} + \frac{\partial \left(D_x(x, t)\frac{\partial C}{\partial x}\right)}{\partial x} + \\ \frac{\partial \left(D_y(y, t)\frac{\partial C}{\partial x}\right)}{\partial y} + \\ \frac{\partial \left(D_z(z, t)\frac{\partial C}{\partial x}\right)}{\partial z} - \\ \frac{\partial \left(u_x(x, t)C\right)}{\partial x} - \\ \frac{\partial \left(u_y(y, t)C\right)}{\partial y} - \\ \frac{\partial \left(u_z(z, t)C\right)}{\partial z} - \frac{\partial^{\alpha} C}{\partial t^{\alpha}} \end{pmatrix} \end{pmatrix} (17)$$

When the embedding parameter p = 0, then Eq. 17 becomes linear as

$$\frac{\partial C}{\partial t} = F\left(x, y, z, t\right) \tag{18}$$

When p=1, Eq. 17 becomes the original Eq. 1. We can

$$C(x, y, z, t) = C_0(x, y, z, t) + pC_1(x, y, z, t) + p^2C_2(x, y, z, t) + p^3C_3(x, y, z, t) + \dots$$
(19)

Now substituting Eq. 19 on Eq. 17 and equating the terms of equal powers of p and using the initial condition we get that:

$$\frac{\partial C_0}{\partial t} = F(x, y, z, t), \quad C_0(x, y, z, 0) = 0$$
(20)

$$\frac{\partial C_{1}}{\partial t} = \frac{\partial C_{0}}{\partial t} + \frac{\partial \left(D_{x}(x,t)\frac{\partial C_{0}}{\partial x}\right)}{\partial x} + \frac{\partial \left(D_{y}(y,t)\frac{\partial C_{0}}{\partial x}\right)}{\partial y} + \frac{\partial \left(D_{z}(z,t)\frac{\partial C_{0}}{\partial x}\right)}{\partial z} \qquad (21)$$

$$\frac{\partial (u_z(z,t)C_0)}{\partial z} - \frac{\partial^{\alpha}C_0}{\partial t^{\alpha}} \qquad C_1(\mathbf{x},\mathbf{y},\mathbf{z},0) = 0$$

$$\frac{\partial C_{2}}{\partial t} = \frac{\partial C_{1}}{\partial t} + \frac{\partial \left(D_{x}(x,t)\frac{\partial C_{1}}{\partial x}\right)}{\partial x} + \frac{\partial \left(D_{y}(y,t)\frac{\partial C_{1}}{\partial x}\right)}{\partial y} + \frac{\partial \left(D_{z}(z,t)\frac{\partial C_{1}}{\partial x}\right)}{\partial z} - \frac{\partial \left(u_{x}(x,t)C_{1}\right)}{\partial x} - \frac{\partial \left(u_{y}(y,t)C_{1}\right)}{\partial y} - \frac{\partial \left(u_{z}(z,t)C_{1}\right)}{\partial z} - \frac{\partial^{\alpha} C_{1}}{\partial t^{\alpha}} \qquad C_{2}(x,y,z,0) = 0$$

$$(22)$$

$$\frac{\partial C_{3}}{\partial t} = \frac{\partial C_{2}}{\partial t} + \frac{\partial \left(D_{x}(x,t)\frac{\partial C_{2}}{\partial x}\right)}{\partial x} + \frac{\partial \left(D_{y}(y,t)\frac{\partial C_{2}}{\partial x}\right)}{\partial y} + \frac{\partial \left(D_{z}(z,t)\frac{\partial C_{2}}{\partial x}\right)}{\partial z} - \frac{\partial \left(u_{x}(x,t)C_{2}\right)}{\partial x} - \frac{\partial \left(u_{y}(y,t)C_{2}\right)}{\partial y} - \frac{\partial \left(u_{z}(z,t)C_{2}\right)}{\partial z} - \frac{\partial^{\alpha}C_{2}}{\partial t^{\alpha}} - C_{3}(x,y,z,0) = 0$$
(23)

Space and time dependent dispersion and velocity component are consider as follows

 $D_{x}(x,t) = D_{x_{0}} x^{2}t, D_{y}(y,t) = D_{y_{0}} y^{2}t,$   $D_{z}(z,t) = D_{z_{0}} z^{2}t, u_{x}(x,t) = U_{x_{0}} xt, u_{y}(y,t) = U_{y_{0}} yt$ and  $u_{z}(z,t) = U_{z_{0}} zt$ , where  $D_{x_{0}}, D_{y_{0}}, D_{z_{0}}, U_{x_{0}}, U_{y_{0}}$ and  $U_{z}$  are constant.

and  $U_{z_0}$  are constant. The space-time dependent source is in the form  $F(x, y, z, t) = x^2 y^2 z^2 t$ , Now solving Eq. 20 to Eq. 23 we get that:

$$C_{0} = \frac{1}{2} \left( x^{2} y^{2} z^{2} t^{2} \right)$$

$$C_{1} = \frac{1}{2} \left( x^{2} y^{2} z^{2} t^{2} \right) + \frac{5}{2} \left( 2R_{1} - R_{2} \right) \frac{x^{2} y^{2} z^{2} t^{4}}{4}$$

$$-x^{2} y^{2} z^{2} t^{3-\alpha} \frac{\Gamma(2)}{\Gamma(4-\alpha)}$$
(25)

$$C_{2} = \frac{1}{2} \left( x^{2} y^{2} z^{2} t^{2} \right) + 4 \left( 2R_{1} - R_{2} \right) \frac{x^{2} y^{2} z^{2} t^{4}}{4}$$
  
+  $\frac{15}{4} \left( 2R_{1} - R_{2} \right)^{2} \frac{x^{2} y^{2} z^{2} t^{6}}{12}$   
-  $3 \left( 2R_{1} - R_{2} \right) x^{2} y^{2} z^{2} t^{4-\alpha} \frac{\Gamma(2)}{\Gamma(5-\alpha)}$ 

$$-x^{2}y^{2}z^{2}t^{3-\alpha}\frac{\Gamma(2)}{\Gamma(4-\alpha)} - \frac{5}{2}(2R_{1}-R_{2})x^{2}y^{2}z^{2}t^{5-\alpha}\frac{\Gamma(4)}{\Gamma(6-\alpha)} + x^{2}y^{2}z^{2}t^{4-2\alpha}\frac{\Gamma(2)}{\Gamma(5-2\alpha)}$$
(26)

$$C_{3} = \frac{1}{2} \left( x^{2} y^{2} z^{2} t^{2} \right) + \frac{11}{2} \left( 2R_{1} - R_{2} \right) \frac{x^{2} y^{2} z^{2} t^{4}}{4} \\ + \frac{27}{2} \left( 2R_{1} - R_{2} \right)^{2} \frac{x^{2} y^{2} z^{2} t^{6-\alpha}}{12} + \frac{27}{4} \left( 2R_{1} - R_{2} \right)^{3} \frac{x^{2} y^{2} z^{2} t^{8}}{16} \\ -9 \left( 2R_{1} - R_{2} \right)^{2} \frac{x^{2} y^{2} z^{2} t^{6-\alpha}}{(6-\alpha)} \frac{\Gamma(2)}{\Gamma(5-\alpha)} \\ -6 \left( 2R_{1} - R_{2} \right) \frac{x^{2} y^{2} z^{2} t^{5-\alpha}}{(5-\alpha)} \frac{\Gamma(2)}{\Gamma(4-\alpha)} \\ -\frac{15}{2} \left( 2R_{1} - R_{2} \right)^{2} \frac{x^{2} y^{2} z^{2} t^{7-\alpha}}{(7-\alpha)} \frac{\Gamma(4)}{\Gamma(6-\alpha)} \\ +3 \left( 2R_{1} - R_{2} \right) \frac{x^{2} y^{2} z^{2} t^{6-2\alpha}}{(6-2\alpha)} \frac{\Gamma(2)}{\Gamma(5-2\alpha)} \\ -3x^{2} y^{2} z^{2} t^{3-\alpha} \frac{\Gamma(2)}{\Gamma(4-\alpha)} \\ -3 \left( 2R_{1} - R_{2} \right) \frac{x^{2} y^{2} z^{2} t^{4-\alpha}}{(4-\alpha)} \frac{\Gamma(2)}{\Gamma(3-\alpha)} \\ -\frac{13}{2} \left( 2R_{1} - R_{2} \right) x^{2} y^{2} z^{2} t^{5-\alpha} \frac{\Gamma(4)}{\Gamma(6-\alpha)} \\ +3x^{2} y^{2} z^{2} t^{4-2\alpha} \frac{\Gamma(2)}{\Gamma(5-2\alpha)} \\ -\frac{15}{4} \left( 2R_{1} - R_{2} \right)^{2} x^{2} y^{2} z^{2} t^{7-\alpha} \frac{\Gamma(6)}{\Gamma(8-\alpha)} \\ +3 \left( 2R_{1} - R_{2} \right) x^{2} y^{2} z^{2} t^{5-2\alpha} \frac{\Gamma(2)}{\Gamma(6-2\alpha)} \\ (27)$$

Where  $R_1$  and  $R_2$  are given by  $R_1 = D_{x_0} + D_{y_0} + D_{z_0}$  And  $R_2 = U_{x_0} + U_{y_0} + U_{z_0}$ We now write the fourth order approximate solution as  $C(x, y, z, t) = C_1(x, y, z, t) + C_2(x, y, z, t)$  (20)

$$C(\mathbf{x}, \mathbf{y}, \mathbf{z}, t) = C_0(\mathbf{x}, \mathbf{y}, \mathbf{z}, t) + C_1(\mathbf{x}, \mathbf{y}, \mathbf{z}, t) + C_2(\mathbf{x}, \mathbf{y}, \mathbf{z}, t) + C_3(\mathbf{x}, \mathbf{y}, \mathbf{z}, t)$$
(28)

Here C(x, y, z, t),  $C_1(x, y, z, t)$ ,  $C_2(x, y, z, t)$  and  $C_3(x, y, z, t)$  are given by Eq. 24, Eq. 25, Eq. 26, and Eq. 27 respectively. A higher order analytical solution may be obtained considering a few more terms.

#### 4.1 Special Case: For Two -and One-Dimensional TFADE

Now, for two-dimensional TFADE, we take  $D_{z_0} = 0$ ,  $U_{z_0} = 0$  and z = 1 in the three-dimensional case we get the solution for two-dimensional TFADE and the solution of the system can be written as follows:

$$C'(x, y, t) = C_0'(x, y, t) + C_1'(x, y, t) + C_2'(x, y, t) + C_3'(x, y, t)$$
(29)

Where  $C_0'(x, y, t)$ ,  $C_1'(x, y, t)$ ,  $C_2'(x, y, t)$  and  $C_3'(x, y, t)$  are given by Eq. 30, Eq. 31, Eq. 32, and Eq. 33 respectively.

$$C_0' = \frac{1}{2} \left( x^2 y^2 t^2 \right) \tag{30}$$

$$C_{1}' = \frac{1}{2} \left( x^{2} y^{2} t^{2} \right) + \frac{5}{2} \left( 2R_{1}' - R_{2}' \right) \frac{x^{2} y^{2} t^{4}}{4}$$
$$-x^{2} y^{2} t^{3-\alpha} \frac{\Gamma(2)}{\Gamma(4-\alpha)}$$
(31)

$$C_{2}' = \frac{1}{2} \left( x^{2} y^{2} t^{2} \right) + 4 \left( 2R_{1}' - R_{2}' \right) \frac{x^{2} y^{2} t^{4}}{4} + \frac{15}{4} \left( 2R_{1}' - R_{2}' \right)^{2} \frac{x^{2} y^{2} t^{6}}{12} -3 \left( 2R_{1}' - R_{2}' \right) x^{2} y^{2} t^{4-\alpha} \frac{\Gamma(2)}{\Gamma(5-\alpha)} - x^{2} y^{2} t^{3-\alpha} \frac{\Gamma(2)}{\Gamma(4-\alpha)} - \frac{5}{2} \left( 2R_{1}' - R_{2}' \right) x^{2} y^{2} t^{5-\alpha} \frac{\Gamma(4)}{\Gamma(6-\alpha)} + x^{2} y^{2} t^{4-2\alpha} \frac{\Gamma(2)}{\Gamma(5-2\alpha)}$$
(32)

$$\begin{aligned} C_{3}^{'} &= \frac{1}{2} \left( x^{2} y^{2} t^{2} \right) + \frac{11}{2} \left( 2R_{1}^{'} - R_{2}^{'} \right) \frac{x^{2} y^{2} t^{4}}{4} \\ &+ \frac{27}{2} \left( 2R_{1}^{'} - R_{2}^{'} \right)^{2} \frac{x^{2} y^{2} t^{6}}{12} + \frac{27}{4} \left( 2R_{1}^{'} - R_{2}^{'} \right)^{3} \frac{x^{2} y^{2} t^{8}}{16} \\ &- 9 \left( 2R_{1}^{'} - R_{2}^{'} \right)^{2} \frac{x^{2} y^{2} t^{6-\alpha}}{(6-\alpha)} \frac{\Gamma(2)}{\Gamma(5-\alpha)} \\ &- 6 \left( 2R_{1}^{'} - R_{2}^{'} \right) \frac{x^{2} y^{2} t^{5-\alpha}}{(5-\alpha)} \frac{\Gamma(2)}{\Gamma(4-\alpha)} \\ &- \frac{15}{2} \left( 2R_{1}^{'} - R_{2}^{'} \right)^{2} \frac{x^{2} y^{2} t^{7-\alpha}}{(7-\alpha)} \frac{\Gamma(4)}{\Gamma(6-\alpha)} \\ &+ 3 \left( 2R_{1}^{'} - R_{2}^{'} \right) \frac{x^{2} y^{2} t^{6-2\alpha}}{(6-2\alpha)} \frac{\Gamma(2)}{\Gamma(5-2\alpha)} \\ &- 3x^{2} y^{2} t^{3-\alpha} \frac{\Gamma(2)}{\Gamma(4-\alpha)} - 3 \left( 2R_{1}^{'} - R_{2}^{'} \right) \frac{x^{2} y^{2} t^{4-\alpha}}{\Gamma(3-\alpha)} \frac{\Gamma(2)}{\Gamma(3-\alpha)} \\ &- \frac{13}{2} \left( 2R_{1}^{'} - R_{2}^{'} \right) x^{2} y^{2} t^{5-\alpha} \frac{\Gamma(4)}{\Gamma(6-\alpha)} \end{aligned}$$

$$+3x^{2}y^{2}t^{4-2\alpha}\frac{\Gamma(2)}{\Gamma(5-2\alpha)}$$
  
$$-\frac{15}{4}(2R_{1}^{'}-R_{2}^{'})^{2}x^{2}y^{2}t^{7-\alpha}\frac{\Gamma(6)}{\Gamma(8-\alpha)}$$
  
$$+3(2R_{1}^{'}-R_{2}^{'})x^{2}y^{2}t^{5-2\alpha}\frac{\Gamma(2)}{\Gamma(6-2\alpha)}$$
(33)

Where  $R'_1$  and  $R'_2$  are given by

 $R'_{1} = D_{x_{0}} + D_{y_{0}}$  and  $R'_{2} = U_{x_{0}} + U_{y_{0}}$ 

Now, for one-dimensional TFADE, we take  $D_{y_0} = 0$ ,  $D_{z_0} = 0$ ,  $U_{y_0} = 0$ ,  $U_{z_0} = 0$  and y = 1, z = 1 the three dimensional case we get the solution for one-dimensional TFADE.

### 5. Discussions

In this study three-dimensional TFADE has been considered to model the system. Spacetime dependent velocity and dispersion is considered to incorporate the heterogeneity in the system. No boundary condition has been specified because for the complex real life system it is not always possible to specify the boundary. Now solving this problem using HPM and plotting these solutions we get the result for variation of fractional order.

We consider dispersion and velocity component as  $D_{x_0} = 0.01$ ,  $D_{y_0} = 0.01$ ,  $D_z = 0.01$  and  $U_{x_0} = 0.001$ ,  $U_{y_0} = 0.001$ ,  $U_{z_0} = 0.001$  respectively. For three-dimensional TFADE, we plot the figures for various fractional orders with space and time using the MatLab software.



Figure 1a: Contaminant concentration distribution profiles against x and y with various fractional order for fixed value of z = 0.1 and fixed time t = 0.1.

We plot Contaminant concentration distribution profiles against x and y with various values of fractional order  $(\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1)$  for fixed value of z = 0.1 and fixed time t = 0.1, for three-dimensional TFADE (Figure 1a). It is clear from the figure that the contaminant concentration increases with the increasing values of x and y. Depending upon the fractional order when the fractional order  $\alpha$  increases then the contaminant concentration decreases. So we get the clear picture how the contaminant concentration depending and changing upon the fractional order i.e., we get a perfect memory from the solution of the system. Similar result observed when we plot Contaminant concentration distribution profiles against x and z with various values of fractional order for fixed value of y = 0.1 and fixed time t = 0.1, and Contaminant concentration distribution profiles against xand z with various values fractional order for fixed value of x = 0.1 and fixed time t = 0.1 for three-dimensional (Figure 1b and Figure 1c).



Figure 1b: Contaminant concentration distribution profiles against x and z with various fractional order for fixed value of y = 0.1 and fixed time t = 0.1.



Figure 1c: Contaminant concentration distribution profiles against y and z with various fractional order for fixed value of x = 0.1 and fixed time t = 0.1.

We plot Contaminant concentration distribution profiles against x and z with various values of fractional order  $(\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1)$  for fixed value of y = 0.1 and fixed time t = 0.1 for three-dimensional TFADE (Figure 1b). From the figure it is clear that the contaminant concentration increases with the increasing values of x and z, contaminant concentration decreases with increasing value of fractional order  $\alpha$ .

In Figure 1c, we plot Contaminant concentration distribution profiles against *y* and *z* with various values fractional order  $(\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1)$  for fixed value of x = 0.1 and fixed time t = 0.1 for three-dimensional TFADE. From the figure, the contaminant concentration increases with the increasing values of *y* and *z* with contaminant concentration decreases with increasing value of fractional order  $\alpha$ .



Figure 2: Contaminant concentration distribution profiles against time for various fractional orders with fixed values of x = 0.5, y = 0.9 and z = 0.9.

We plot Contaminant concentration distribution profiles against time with various values fractional order ( $\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1$ ) for fixed values of x = 0.5, y = 0.9 and z = 0.9 for three-dimensional TFADE (Figure 2). From the figure it is clear that the contaminant concentration starting from zero increases with the increasing values for time and contaminant concentration decreases with increasing value of fractional order  $\alpha$ .

Now for two-dimensional TFADE, we take  $D_{z_0} = 0$ ,  $U_{z_0} = 0$  and z = 1 in the three-dimensional case we get the solution for two-dimensional TFADE. We consider the dispersion and velocity components  $D_{x_0} = 0.01$ ,  $D_{y_0} = 0.01$  and  $U_{x_0} = 0.001$ ,  $U_{y_0} = 0.001$ .



Figure 3: Contaminant concentration distribution profiles against *x* and *y* with various fractional order fixed time t = 0.01.

We plot Contaminant concentration distribution profiles against x and y with various values of fractional order ( $\alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1$ ) and fixed time t = 0.01 for two-dimensional TFADE (Figure 3). Ssimilar result has been obtained as before we see that contaminant concentration decreases with increasing values of fractional order  $\alpha$ .



Figure 4: Contaminant concentration distribution profiles against time for various fractional orders with fixed values of x = 0.5, y = 0.15.

We plot Contaminant concentration distribution profiles against time with various values fractional order ( $\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1$ ) for fixed value of x = 0.5, y = 0.15 for two-dimensional TFADE (Figure 4). In Figure 4 contaminant concentration is depicted with time for a fixed point and we see that starting from zero contaminant concentration increases depending upon the fractional order. It is clear from the study that when the fractional order increases then contaminant concentration decrease. So, we

inversely proportional to the fractional order  $\alpha$ . Now for one-dimensional TFADE, we take  $D_{y_0} = 0$ ,  $D_{z_0} = 0$ ,  $U_{y_0} = 0$ ,  $U_{z_0} = 0$  and y = 1, z = 1 in the three dimensional case, we get the solution for one-dimensional TFADE. We consider the dispersion and velocity components  $D_{x_0} = 0.01$ and  $U_{x_0} = 0.001$ .

get that the contaminant concentration level is



Figure 5: Contaminant concentration distribution profiles against x and y with various fractional order and fixed time t = 0.1.



Figure 6: Contaminant concentration distribution profiles against time for various fractional orders with fixed values of x = 1.

We plot Contaminant concentration distribution profiles against x with various values of fractional order ( $\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1$ ) and fixed time t = 0.1 for one-dimensional TFADE (Figure 5). In Figure 5, contaminant concentration with distance has been depicted and similar result is obtained. It is clear from the figure that when fractional order increases then contaminant concentration decreases.

We plot Contaminant concentration distribution profiles against time with various values fractional order ( $\alpha = 0.2, \alpha = 0.4, \alpha = 0.6, \alpha = 0.8, \alpha = 1$ ) for fixed value of x = 1 for one-dimensional TFADE (Figure. 6). Contaminant concentration with time is depicted in Figure 6 and it is clear from the figure that when fractional order increases the contaminant concentration decreases. The growth of the contaminant concentration is slow up to t=0.4 then the concentration profile increases rapidly.

# 6. Conclusion

This study presented a mathematical model of mixed soil type aquifer zone with nearby large water bodies. Modelled mathematical system presented the solution of three dimensional TFADE with space-time dependent source with the help of HPM. Two-dimensional and one-dimensional TFADE also derived from the solution of three dimensional TFADE which may describe the modelled system in two and one dimension respectively. In all three cases spacetime dependent velocity and dispersion profile considered throughout the aquifer to model the contaminant transport in heterogeneous porous formation. Also in all figure, when  $\alpha = 1$  represents the contaminant concentration distribution for normal three-dimensional ADE. The contaminant concentration is going to increase with respect to distance and also see that when the fractional order increases the level of contaminant concentration decreases for a fixed time. Contaminant concentration increases with increasing time and decreases with increasing fractional order for a fixed point. One clear picture of relationship between the contaminant concentration and fractional order has been obtained. A perfect memory of the solution with fractional order has been observed. This type of TFADE can be used to model the complex realworld problem with full of heterogeneity. We can also conclude that the HPM will be more accurate when the number of approximation term increased in the series solution.

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# 76. Kalman filter based multiple object tracking using Hungarian algorithm and performance tuning using RMS index

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#### Abstract

Object tracking assumes a crucial role in a wide array of computer vision and robotics applications, including surveillance, autonomous navigation, and human-computer interaction. The Kalman Filter (KF) has emerged as a leading instrument for object tracking, distinguished by its efficiency and adaptability in managing noisy measurements and dynamic environments. In this study, we leverage the capabilities of the Kalman Filter for tracking both simulated objects and real-life video tracking in a 2D context. Employing the concept of the Root Mean Square (RMS) index, we fine-tune the Kalman filter to yield optimal results, tailored to specific parameter requirements. The paper commences with an extensive exposition of the Kalman Filter, delving into its mathematical foundations and core principles. Subsequently, it elucidates the concept of the RMS index and introduces an algorithm that combines both elements into a unified approach. Furthermore, this research harnesses the Hungarian algorithm to track multiple objects within video footage. A comprehensive comparative analysis of results under different tuning parameters demonstrates the superior performance of the customized parameter settings within specific scenarios. Ultimately, our findings affirm that a properly tuned Kalman Filter operates on low-power computation and provides exceptional efficiency in contrast to alternative methodologies.

Keywords: Kalman Filter, Object Tracking, RMS index, 2D Tracking, Hungarian Algorithm

# 1. Introduction

Object Tracking plays a crucial role in various applications within the realm of computer vision. Object Tracking algorithms have garnered significant attention with the advancement of powerful computing systems, the widespread accessibility to affordable enhanced cameras, and the growing urge for automated footage analysis (Cedras & Shah 1995; Yilmaz et al. 2006). Among the myriad tracking algorithms available, the Kalman Filter (KF) has consistently emerged as a powerful tool due to its efficiency and adaptability in handling noisy measurements and dynamic environments (Basso et al. 2017; Jiao & Wang 2022; Mirunalini et al. 2017). This section aims to provide insights into the latest developments in Kalman Filter-based object tracking, highlighting its advantages over alternative methods, and offering a selection of recent references that reflect the current state of the field. Particle filters are a popular alternative to the traditional KF for non-Gaussian tracking problems. While particle filters can handle non-linearities and multi-modal distributions better than Kalman Filters, they suffer from high computational complexity (Bukey et al. 2017). Mean-shift tracking is particularly effective for object tracking in cluttered scenes and handles appearance changes well. However, mean-shift may struggle with scale variations and abrupt object motion (Kumar et al. 2020). Template matching is simple and computationally efficient, but can be sensitive to variations
in object appearance, illumination changes, and occlusions.

In summary, while there are various object tracking methods available, the Kalman Filter remains a popular choice for object tracking due to its computational efficiency, simplicity, and noise-handling capabilities. While other methods like particle filters and meanshift tracking excel in specific scenarios, the Kalman Filter offers a balanced approach suitable for a wide range of tracking applications (Barrau & Bonnabel 2016; Jondhale et al. 2018; Mahalingam & Subramoniam 2020; Xu & Chang 2014).

#### 2. Theoretical Background

In this section, the paper discusses the underlying theory of object tracking using KF and various other process components related to the overall scope of the paper. The section concisely overviews the Kalman Filter theory (Bukey et al. 2017) and the RMS index (Saho & Masugi 2015). It's worth noting that more in-depth explanations of these topics can be found in other papers (Chen et al. 2019; Fauzi et al. 2023; Saho 2018; Saho & Masugi 2015; Yang et al. 2019), as they exceed the scope of this one. The section also includes the presentation of equations for tracking an object in two dimensions and the introduction of the blob detection algorithm, which is used to detect simulated objects or blobs in a uniform background. Additionally, in order to achieve real video tracking, the paper makes use of the Hungarian algorithm (Hamuda et al. 2018) in tandem with the foundational KF theory, as discussed earlier. It is important to highlight that real-time video tracking leverages pre-trained weights from a Deep Neural Network (DNN) (Erol et al. 2018; Szegedy et al. 2018) implemented using the OpenCV library in Python. These pre-trained weights aid in object detection, generating the measurements essential for the functioning of the Kalman Filter system.

#### 2.1 Kalman Filter

The KF works in two main parts: prediction and update. The state prediction is given by Equation (1) and covariance prediction is given by Equation (2):

$$\hat{x}_{k}^{-} = \varphi \hat{x}_{k-1}^{+} + B u_{k-1} \tag{1}$$

$$\hat{P}_k^- = \varphi \hat{P}_{k-1}^+ \varphi^T + Q \cdot \tag{2}$$

where is the predicted state vector, is the process transition matrix, is the input matrix, is the input, is the predicted covariance matrix, and is the process noise covariance matrix. in the suffix denotes the time epoch. For the KF updation step, the necessary equations, namely, measurement residual, residual covariance, Kalman gain, state update, and covariance update are given from Equation (3) to Equation (7) respectively:

$$y_k = z_k - H\hat{x}_k^- \tag{3}$$

$$S_{-} = H\hat{P}^{-}H^{T} + R \tag{4}$$

$$K_k = \hat{P}_k^- H^T S_k^{-1} \tag{5}$$

$$\hat{x}_k^+ = \hat{x}_k^- + K_k y_k \tag{6}$$

$$P_{k}^{+} = (I - K_{k}H)P_{k}^{-}(I - K_{k}H)^{T} + K_{k}R_{k}$$
(7)

where is the measurement vector, is the measurement matrix, is the measurement noise covariance, is the measurement residual, is the residual covariance, is the Kalman gain, is the updated state vector, and is the updated covariance matrix. in the suffix denotes the time epoch.

Considering a 2D tracking system, the following KF equations are derived from the standard KF equations. The state vector can be extended to the previous state at time, using Equation (8). Here, and are the concerned variables denoting the object position and is the sampling interval.

$$X_{t} = \begin{bmatrix} x_{t} \\ y_{t} \\ y_{t} \\ y_{t} \\ y_{t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & dt & 0 \\ 0 & 1 & 0 & dt \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_{t-1} \\ y_{t-1} \\ \dot{x}_{t-1} \\ \dot{y}_{t-1} \end{bmatrix} + \begin{bmatrix} \frac{1}{2} dt^{2} & 0 \\ 0 & \frac{1}{2} dt^{2} \\ dt & 0 \\ 0 & dt \end{bmatrix} \begin{bmatrix} \ddot{x}_{t-1} \\ \ddot{y}_{t-1} \end{bmatrix}$$
(8)

From Equation (8), it is clear that:

$$\varphi = \begin{bmatrix} 1 & 0 & dt & 0 \\ 0 & 1 & 0 & dt \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} and B = \begin{bmatrix} \frac{1}{2}dt^2 & 0 \\ 0 & \frac{1}{2}dt^2 \\ dt \\ 0 & dt \end{bmatrix}$$

Since, only using only the position parameters are recorded for measurement, H can be stated as:

$$H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \end{bmatrix}$$
(10)

Also, the standard process noise covariance, Q and measurement noise covariance, R for 2D tracking are given by Equation (12) and (11).  $6^{-2}$  is the parameter that is needed to be tuned to<sup>x</sup> get the best KF outcome.  $6^{2}_{x}$  and  $6^{2}_{y}$  are the variances for measurements in x and y coordinates.

$$R = \begin{bmatrix} \dot{\mathbf{o}}_{x}^{2} & \mathbf{0} \\ \mathbf{0} & \dot{\mathbf{o}}_{y}^{2} \end{bmatrix}$$
(11)

$$Q = \begin{bmatrix} \frac{dt^4}{4} & 0 & \frac{dt^3}{2} & 0\\ 0 & \frac{dt^4}{4} & 0 & \frac{dt^3}{2}\\ \frac{dt^3}{2} & 0 & dt^2 & 0\\ 0 & \frac{dt^3}{2} & 0 & dt^2 \end{bmatrix} \dot{6}_{x}^{2}$$
(12)

#### 2.2 RMS Index

To calculate the RMS index for a POM system (Saho 2018), the KF estimates the true state of the system based on the available measurements at time k, and then the estimated state is compared to the true state over a specific period of time. The RMS index is to be calculated for varying values of Q prior to running the KF. The Q for which RMS index provides the least value is then used to run the KF tracking system. The detailed algorithm to calculate RMS index can be found in (Saho 2018; Saho & Masugi 2015). Assuming that the process noise in x and y coordinates are similar, Q for one-dimensional (1D) tracking can be extracted from previous equations, and can be expressed as

$$\begin{bmatrix} \frac{dt^4}{4} & \frac{dt^3}{2} \\ \frac{dt^3}{2} & dt^2 \end{bmatrix} \times \sigma_q^2$$

or  $\begin{bmatrix} a & b \\ b & c \end{bmatrix}$ . Now, considering the above expression,

RMS index can be calculated using the following expression:

$$\mu_p = \frac{a_D^2}{\beta^2} + \frac{2\alpha^2 + 2\beta + \alpha\beta}{\alpha(4 - 2\alpha - \beta)}$$
(13)

where,

$$\beta = \frac{C + \sqrt{C(16 + 4A - 4B + C)}}{4}$$
$$- \sqrt{\frac{C^2(16 + 4A - 4B + C)}{8\sqrt{C(16 + 4A - 4B + C)}}} + \frac{C(2A - 2B + C)}{8}$$

$$\alpha = 1 - \frac{\beta^2}{C} \tag{15}$$

and, A = 
$$\frac{a}{B_x}$$
, B =  $\frac{bdt}{B_x}$ , C =  $\frac{cdt^2}{B_x}$ ,  
 $a_D^2 = a_c^2 dt^4 / B_x$ 

Here,  $a_c$  is assumed to be the constant acceleration of the moving object, which is assumed to be estimated.  $B_x$  is the measurement noise variance, i.e.,  ${\delta_x}^2$  or  ${\delta_y}^2$ , with the assumption that both the measurement noise variances are equal. If in case, either of measurement noise variance or process noise variance for x and y coordinates differ, then two separate RMS indices needs to be calculated. The choice to assume equal noise variances for simplicity in practical object tracking is made with this context in mind.

#### 2.3 Blob Detection and Hungarian Algorithm

A basic blob-detecting algorithm is applied to detect moving circles in a video sequence, on which the 2D tracking test is performed. This method finally outputs the centroid of the object, which is used in the KF measurement model. The first step is to convert the image from color to grayscale which simplifies the image by removing color information. Then, a suitable edge detection algorithm, vis., the Canny edge detector (Sekehravani et al. 2020) or Sobel operator (Han et al. 2020), is applied to the grayscale image which highlight areas of significant intensity variation, denoting edges or boundaries of objects. After converting the image to binary, contour detection algorithms, such as the OpenCV function findContours(), are applied. Finally, detected contours are used to identify blobs or objects.

When detecting multiple objects in a frame, the image processing algorithm treats each frame as an isolated task, providing centroids in the order of detection, thus failing to track multiple objects. The challenge is to accurately assign IDs to objects detected in the next frame. Considering objects detected in two consecutive frames, with edges indicating potential matches based on Euclidean distances, the objective is to find the minimum-weight matching to correctly ID objects from past frame to current. To address this issue efficiently, the Hungarian algorithm (Hamuda et al. 2018) is employed, processing the bipartite graph represented as an adjacency matrix.

#### 2.4 Proposed Model

The diagram in Figure 1 shows the detailed block diagram to track multiple objects in a video sequence.



Figure 1. Block diagram for Object Tracking

The main block is responsible for sending image frames and generating output video. Object Tracker keeps tabs on objects by using the Hungarian algorithm mentioned in above section. Meanwhile, the Kalman filter predicts and figures out where each object is in the next frames, using data and a model. This filter's accuracy is adjusted using the RMS index, calculated using the method explained in above section. Finally, the detection block, as described in above section, identifies the center points of objects for tracking by using edge detection.

# 3. Results and Discussion

#### 3.1 Simulated Object 2D Tracking

Figure 2 presents a visual representation of a frame, displaying both the actual measured position and the predicted estimated position. In Figure 3, there's a plot that charts the coordinates of an object moving in two dimensions, comparing the estimated and measured values. Figure 4 provides a graphical depiction of how far the object's position deviates from the true coordinates, showing the absolute deviation.



Figure 2 Graphical Representation of 2D Tracking



Figure 3 Estimated Path vs. True Path



Figure 4 Error deviation from True Path

Table 1 shows the various errors for different Q values, thus concluding that the tuned Q for p = 1, which is derived from the discussed algorithm provides the best result. The term p is used in context of the relation  $(Q = Q_{nom} \times 10^p)$  using which Q is varied, where  $Q_{nom}$  is the nominal Q.

p value	RMS Index	Abs. Mean Error (cm)			
-1	11.6	7.73			
0	1.49	4.90			
1	0.79	2.89			
2	1.67	5.02			
3	4.62	7.10			

Table 1: Performance comparison for different Q values

#### 3.2 Real Video Tracking

Figure 5 displays the tracking simulation of a sample video in sequence. Here the same algorithm is used as discussed in the methodology section of the paper. The extra layer that is integrated to do so uses the DNN-based detection technique using pre-trained weights, which is integrated within the KF measurement model.



Figure 5 Real Video Tracking

# 4. Conclusion and Future Work

In our exploration of object tracking using the Kalman filter, we conducted a comprehensive analysis. Our findings from the simulation results are significant. It is evident that the Kalman filter performs exceptionally well when certain conditions are met: the system model is linear, the noise distribution is assumed to be of Gaussian nature, and the filter is finely tuned. We have also addressed the challenge of Multiple Object Tracking, by efficiently applying the Hungarian algorithm. Tuning the filter's noise parameters of the KF can be a complex endeavor, and in this thesis, we have introduced an approach to automatically adjust the process noise covariance matrix, Q. Our results demonstrate that with proper tuning, a poorly performing system can experience a substantial enhancement in its overall performance.

For future research, this method can be further explored, tested, and adapted to non-linear and more intricate models to assess its versatility. Additionally, the algorithm's suitability for different variants of the Kalman filter, such as the Extended Kalman Filter (EKF) or Unscented Kalman Filter (UKF), could also be investigated.

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# 77. Analyzing EEG signals using multifractal analysis

# Distinguishing alpha and theta rhythms in relaxation and classical music listening

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### Abstract

Music continues to serve as a valuable therapeutic tool for individuals grappling with cognitive impairments and neurological conditions. Nevertheless, the intricate mechanisms through which music impacts brain frequencies remain largely enigmatic. This electroencephalography (EEG) study endeavors to unravel the spatio-temporal intricacies of slow and fast brain frequencies during music listening. EEG signals are currently being recorded from twenty-five healthy human subjects for two minutes under two conditions: first, with their eyes closed in a relaxed state (without music), and second, while listening to classical instrumental music (sitar) with their eyes closed. Data collection is conducted at the CPEPA laboratory, University of Calcutta, Kolkata, India. The Wavelet Transform (WT) technique has been applied to separate alpha and theta waves from the EEG signal. Multifractal Detrended Fluctuation Subsequently, Multifractal Detrended Fluctuation Analysis (MFDFA) is employed to scrutinize the spatial and temporal intricacies in their complexity. Furthermore, repeated measures ANOVA tests are administered to assess the statistical significance of the findings within and between the two states. Preliminary results disclose that the Hurst exponent in both experimental states is nearly identical. Moreover, the theta band exhibits a markedly higher degree of multifractality when compared to the alpha band. A significant revelation stemming from this study is the substantial divergence in multispectral widths among electrodes located in the frontotemporal (T3, T4), temporoparietal (T5), and central (Cz) regions between the two experimental states. These findings significantly bolster the foundation for future research exploring the potential effectiveness of rhythm- and music-based interventions in the rehabilitation and cognitive retraining of individuals grappling with impairments.

Keywords: Classical instrumental (sitar), EEG, alpha and theta rhythms, MFDFA.

## 1. Introduction

Music has been used for therapeutic purposes across cultures throughout history, but the precise mechanisms of music therapy remain unclear. In the early 1990s, research on the brain's response to music gained traction, revealing that music can influence various brain regions and neural networks (Koelsch, 2010; Koelsch and Siebel 2005). Music therapy, an affordable psychosocial intervention, has shown promise in managing symptoms of schizophrenia and promoting social interaction and neurophysiological function (Gold, Solli, Kruger and Lie 2009; Peng, Koo, and Kao 2010).

Electroencephalogram (EEG) records electrical signals from the brain, offering insights into neural activity and consciousness levels (Light,

Williams, Minow, Sprock, Rissling, et al. 2010; Nunez, and Srinivasan 2006). EEG analysis, including linear and nonlinear methods, has examined different frequency bands such as delta, theta, alpha, beta, and gamma. Wavelet transform (WT) is a valuable tool for EEG data analysis, focusing on alpha and theta frequencies due to their role in emotion processing during music listening (Pachori, and Bajaj 2011; Jacobs and Friedman 2004; Marzuki, Mahmood, and Safri 2013). Studies have shown changes in these frequency bands in response to music (Banerjee, et al 2016; Lopes and Betrouni 2009). Frontal areas of the brain, particularly the frontal midline theta power, play a key role in emotional processing during music listening (Schacter 1977). Pleasant music can influence alpha and theta power, indicating emotional responses (Pavlygina, Sakharov, and Davydov. 2004).

Peng et al. (Peng et al. 1994) introduced the detrended fluctuation analysis (DFA) methodology to study the properties of DNA sequences. But the problem with DFA is that data was not analyzed in different scaling exponents, so many interwoven fractal subsets of the time series remains unrevealed. The multifractal detrended fluctuation analysis (MFDFA) was first developed by Kantelhardt et al. (Kantelhardt et al. 2002) as a generalization of the standard DFA. MFDFA is efficient of controlling multifractal scaling behaviour of a non-stationary timeseries. MFDFA is one of the most advanced nonlinear tools found till date for studying non-linear, non-stationary EEG dynamics. Its application found in various studies (Kantelhardt et al. 2003; Kantelhardt et al 2006; Telesca, Lapenna, et al. 2004; Uthayakumar, and Easwaramoorthy. 2013; Gaurav, Anand, and Kumar. 2021). But there are very few studies conducted in the non-linear domain, which reported the effect of musical stimuli on the EEG brain waves (Telesca, Lapenna, et al. 2004).

This study focused on classical instrumental music (sitar) and utilized MFDFA to analyze EEG signals in a healthy control group. The research aimed to identify brain regions with significant alpha and theta waves differences between resting and music listening states. The differences between EEG signals were identified using a robust non-linear analysis technique like MFDFA and also the repeated measures ANOVA was used to compare the mean multi-fractal widths between the states.

# 2. Materials and Methods

# 2.1 Subjects

Twenty-five healthy subjects (13 female, 12 male) aged 23 to 29 (mean age 25, S.D 5years) with normal hearing and no history of psychiatric diseases, medication use, or hearing aids participated in the study. All subjects were research scholars at Calcutta University (Rajabazar Campus), Kolkata, West Bengal, India. Ethical approval was obtained from the University of Calcutta, and the experiments were conducted at the CPEPA Laboratory, Rajabazar Campus.

# 2.2 Experimental Details

EEG signals are recorded using an Electro-Cap International 36-electrode (provided by Axxonet system technologies). Recordings are made in a soundproof room with controlled temperature and light. All EEG signals are recorded following the International 10-20 montage system covering all the brain's cortical areas. The EEG data is extracted through the 19 electrodes viz. Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T3, T4, T5, T6, Fz, Cz and Pz. All silver/ silver chloride electrodes are referenced to the left ear (Clarke et al., 2002). The EEG signals are sampled at a rate of 256 Hz. A Butterworth filter of 0.05 to 30 Hz is applied, and a notch filter is set at 50 Hz.

Classical instrumental sitar music was played through headphones during the experiment. The recording consisted of two phases: 2 minutes of EEG recording in a relaxed, eyes-closed state (without music) followed by 2 minutes of EEG recording with the subject listening to classical music after a 2-minute break.

#### 2.3 Preprocessing

EEG signals for each subject undergo manual preprocessing in MATLAB (version R2021b), with artifact epochs rejected using EEGLAB software (2022) (Delorme and Makeig, 2004). The preprocessing pipeline, designed by experts, involves several crucial steps. Firstly, a highpass filter with a 0.1 Hz cutoff frequency eliminates low-frequency drift and baseline wander,

focusing on higher-frequency neural activity. Secondly, line noise artifacts at frequencies like 60 Hz or 120 Hz are removed using techniques like notch or adaptive filtering, enhancing signal quality. Thirdly, problematic channels are interpolated to maintain electrode montage integrity. Rereferencing to an average reference reduces common noise sources' impact. Independent Component Analysis (ICA) decomposes EEG signals into independent components, aiding artifact separation. Manual ICA component analysis identifies and discards non-brain-related artifacts like eye blinks or muscle activity, ensuring artifact-free EEG signals for analysis. This comprehensive preprocessing ensures the accuracy and reliability of subsequent neural analyses.

#### 2.4 Wavelet Transform

The EEG signals were subjected to Discrete Wavelet Transform (DWT) to decompose them into different scales. DWT provided both time series data and amplitude envelopes. The amplitude envelopes of the alpha (8-13Hz) and theta (4-8 Hz) frequency bands were extracted using DWT from 19 electrodes.

# 2.5 Multifractal Detrended Fluctuation Analysis (MFDFA)

MFDFA was employed to analyze the amplitude envelopes of alpha and theta frequencies obtained via wavelet transform. Each 30-second segment was divided into 5 non-overlapping windows of 6 seconds each, and the results were averaged. MATLAB R2016a was used for analysis. The detailed MFDFA will be found in Kantehardt et al. (Kantelhardt et al. 2003).

In general, two different types of multifractality are present in a time series data: (i) multifractality of a time series can be due to a broad probability density function for the values of the time series, and (ii) multifractality can also be due to different long-range correlations for small and large fluctuations (Kantelhardt et al 2003). To find which types of multifractality present in the series, we will randomly shuffled the series. The averaged result was considered for analysis from surrogate data, which were shuffled 1500 times for each segment of original EEG. In the shuffling procedure all the correlations were destroyed.

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#### 2.6 Statistical Analysis

Repeated measures ANOVA was conducted to compare means within and between groups. The analysis focused on EEG signals in the relaxed (without music) and music-listening states, specifically examining the alpha and theta bands. SPSS 16.0 software was used for statistical analysis.

# 3. Results and Discussion

#### 3.1 Visualization of EEG Amplitude Envelopes

Representative figures were provided to illustrate the amplitude envelopes of alpha and theta waves in a single subject for relaxation (without music) and music-listening states. The visualizations displayed in figure 1 show how EEG signals change in response to the presence of classical music.



Figure 1: 6s alpha amplitude envelope of (a) relax state and (b) listening music state.

#### 3.2 Analysis of q-th Order Fluctuation Functions

Please modify the section to "The q-th order fluctuation functions (Fq(s)) were computed for different q values, including -5, -3, 0, +3, and +5. These functions demonstrate the scaling behavior of EEG signals in both alpha and theta



**Figure 2:** Sample regression plots log2(s) vs. log2(Fq) of alpha band for (a) relax state and (b) listening music state.

bands. The log-log plots of Fq(s) vs. log2(s) revealed a linear relationship, indicating scaling behavior in figure 2.

#### 3.3 Hurst Exponents Analysis

Hurst exponents (h(q)) were calculated for a specific electrode (T3) in both relaxation and music-listening states. The h(q) variation with q demonstrated multifractal behavior in both states. The comparison with shuffled values, which were approximately 0.55, confirmed the multifractal scaling. The presence of multifractality indicated that EEG signals exhibited different long-range correlations for small and large fluctuations, which is shown in figure 3.



**Figure 3:** Variation of Hurst exponent h(q) with q for alpha and theta (a) relax state and (b) listening music state in part-1. Color code: Blue: original h(q) values of alpha band, Red: original h(q) values of theta band, Green : shuffled h(q) values of alpha ban

#### 3.4 Singularity Spectrum Analysis

The singularity spectrum  $(\tau(q))$  was analyzed as a function of q, showing evidence of multifractal patterns in both alpha and theta bands during relaxation and music-listening states. Multifractality was stronger in certain scales during relaxation and in others during music listening, indicating complexity differences between the two states, which is shown in figure 4.



Figure 4: Variation of  $\tau$  (q) with q for alpha and theta band in relax and listening music states.

#### 3.5 Quantifying Multifractality

The multifractal spectrum width ( $\Delta \alpha$ ) was used to quantify the amount of multifractality in EEG signals. A broader spectrum indicated stronger multifractality, while a narrower spectrum suggested weaker multifractality. The figure 5 shows that the average width of each of the five windows was obtained, and wider widths indicated higher complexity.



**Figure 5:** Multifractal spectrum of (a) relax state and (b) listening music state. Color code: Blue circle: original h(q) values of alpha band, Red circle: original h(q) values of theta band, Green plus: shuffled h(q) values of alpha band, Magenta plus: shuffled h

#### 3.6 Statistical Analysis

Repeated measures ANOVA was performed to assess the statistical significance of differences within and between states (relaxation and music listening). The analysis focused on alpha and theta bandwidths. Significant differences were found in alpha and theta band widths within both states. Moreover, differences in multifractal widths between states were observed in specific brain regions, such as frontotemporal, temporoparietal, and central regions, clearly displayed in figure 6.



**Figure 6:** Alpha and theta spectral width for relax and listening music state. Red line square marker: alpha width in relax state, Blue line square marker: alpha width in listening music state, Red line round marker: theta width in relax state and Blue l

Table 1 shows Multifractal spectral Mean + S.d width for the all the electrodes. Table represents within state (alpha and theta band of relaxing state and listening music state) effects.

Table 1:	Multifract	tal spectral Me	an + S.d w	idth for the	all the	e electrodes.	Table rep	oresents	within s	state
(alpha an	id theta ba	nd of relaxing	state and l	istening mu	isic sta	te) effects.				

Relax state					Listening music state				
Electrode		Original Width	Shuffled Width		Original Width	Shuffled Width	F	<i>p</i> -value	
Fp1	Alpha	0.786 ±	0.08	0.179	0.834±0.08	0.176	15.096	0.001**	
	Theta	0.875 ±	0.07	0.172	0.907± 0.07	0.180			
Fp2	Alpha	0.788 ±	0.11	0.162	0.814 ±0.09	0.172	28.425	0.001**	
	Theta	0.914 ±	0.10	0.174	0.914± 0.10	0.176			
F3	Alpha	0.800 ±	0.07	0.172	0.774± 0.07	0.183	19.766	0.001**	
	Theta	0.879 ±	0.07	0.169	0.869± 0.06	0.170			
F4	Alpha	0.770 ±	0.06	0.171	0.776 ±0.07	0.179	17.235	0.001**	
	Theta	0.916 ±	0.10	0.182	0.857± 0.08	0.180			
C3	Alpha	0.798 ±	0.08	0.172	0.740± 0.09	0.166	30.464	0.001**	
	Theta	0.896 ±	0.10	0.171	0.927± 0.06	0.179			
C4	Alpha	0.769 ±	0.04	0.176	0.778 ±0.07	0.172	28.083	0.001**	
	Theta	0.917 ±	0.10	0.168	0.914± 0.05	0.177			
P3	Alpha	0.784 ±	0.07	0.173	0.752± 0.09	0.186	21.604	0.001**	
	Theta	0.910 ±	0.09	0.170	0.892± 0.07	0.174			
P4	Alpha	0.739 ±	0.06	0.166	0.731 ±0.06	0.175	34.541	0.001**	
	Theta	0.909 ±	0.09	0.172	0.903± 0.08	0.180			
01	Alpha	0.772 ±	0.07	0.179	$0.758 \pm 0.09$	0.162	26.829	0.001**	
	Theta	0.885 ±	0.06	0.180	$0.902 \pm 0.08$	0.177			
O2	Alpha	0.793 ±	0.06	0.175	0.789 ±0.09	0.176	30.520	0.001**	
	Theta	0.903 ±	0.08	0.173	$0.909 \pm 0.08$	0.179			
F7	Alpha	0.824 ±	0.18	0.165	$0.794 \pm 0.10$	0.171	11.286	0.001**	
	Theta	0.933 ±	0.08	0.174	$0.898 \pm 0.07$	0.168			
F8	Alpha	0.787±	0.14	0.172	$0.824 \pm 0.07$	0.173	10.458	0.001**	
	Theta	0.885 ±	0.05	0.168	$0.907 \pm 0.08$	0.174			
T3	Alpha	0.840 ±	0.07	0.177	$0.802 \pm 0.04$	0.166	7.560	0.012**	
	Theta	0.897 ±	0.08	0.167	0.866± 0.06	0.181			
T4	Alpha	0.766 ±	0.06	0.174	$0.770 \pm 0.08$	0.178	40.810	0.001**	
	Theta	0.898 ±	0.08	0.179	$0.910 \pm 0.08$	0.171			
T5	Alpha	0.737 ±	0.03	0.177	$0.771 \pm 0.05$	0.168	0.013	0.909	
	Theta	0.913 ±	0.07	0.175	$0.874 \pm 0.08$	0.178			
T6	Alpha	0.791 ±	0.07	0.179	$0.780 \pm 0.07$	0.162	32.855	0.001**	
	Theta	0.896 ±	0.07	0.181	$0.882 \pm 0.05$	0.173			
Fz	Alpha	0.818 ±	0.06	0.180	$0.770 \pm 0.06$	0.179	19.005	0.001**	
	Theta	0.902 ±	0.08	0.181	0.910± 0.09	0.171			
Cz	Alpha	0.771 ±	0.05	0.171	0.750± 0.07	0.183	31.010	0.001**	
	Theta	0.949 ±	0.10	0.189	0.883± 0.06	0.172			
Pz	Alpha	0.776 ±	0.07	0.173	$0.737 \pm 0.07$	0.179	43.823	0.001**	
	Theta	0.916 ±	0.07	0.171	0.918± 0.08	0.177			
All <i>p</i> -values v	vere corrected	via Greenhous	se-Geisser me	ethod.					

\* significant p < 0.05 and \*\* significant p < 0.01

Table 2 shows the Test statistic from ANOVA. F -statistic and p-value represent between state (relaxing and listening music state) effects.

**Table 2:** Test statistic from ANOVA. F -statistic and p-value represent between state (relaxing and listening music state) effects.

Electrode	F	р
Fp1	2.427	0.135
Fp2	0.106	0.748
F3	0.663	0.425
F4	1.96	0.177
C3	0.215	0.648
C4	0.330	0.857
P3	1.411	0.248
P4	1.411	0.181
01	0.458	0.506
O2	0.011	0.976
F7	0.744	0.399
F8	0.987	0.332
Т3	0.617	0.221*
T4	0.121	0.731
Т5	53.34	0.001**
Т6	0.212	0.652
Fz	1.094	0.308
Cz	4.698	0.042 *
Pz	0.795	0.383

# 4. Conclusion

In this study, Multifractal Detrended Fluctuation Analysis (MFDFA) was employed to differentiate spatio-temporal pattern of theta and alpha brain waves during relaxation (without music) and classical music listening (sitar) states. The Hurst exponent exhibited similar values in both experimental states. Notably, alpha spectral width decreased in the relaxation state compared to music listening in temporoparietal electrodes T5 and T6, indicating increased alpha band multifractality during music listening in this brain region. Repeated measures ANOVA confirmed significant differences in multifractal width within alpha and theta bands across electrodes. Shuffled series analysis suggested multifractality stemmed from long-range correlations and a broad probability distribution. Theta band spectral width exceeded alpha in both states, signifying higher multifractality. Significant differences

between relaxation and music listening states were observed in frontotemporal (T3, T4) and temporoparietal (T5) lobes, emphasizing their role during classical music listening. Our findings underscore the potential of EEG in elucidating brain mechanisms related to music, offering insights for cognitive music therapies and emotion research. Future studies should explore various music genres and instruments while extending research to individuals with mental health conditions for therapeutic insights.

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# 78. Dynamics of an eco-epidemic model considering nonhereditary disease in the prey population

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#### Abstract

This paper presents and dynamically investigates a mathematical model of a prey-predator system in which prey is infected by a nonhereditary disease but capable of reproducing by logistic expansion. So, the newborns through the infected class go to the susceptible class. The basic reproduction number is evaluated to obtain the threshold condition for the disease endemicity. The existence and positive invariance, uniform boundedness, local stability, and global stability of the model system are studied. All the analytical results are confirmed by numerical simulation. The numerical investigation also ensures the existence of Hopf-bifurcation and Transcritical bifurcation. Finally, some important eco-epidemiological viewpoints of the obtained results are concluded.

Keywords: Eco-epidemiology, Nonhereditary disease, Boundedness, Stability, , Bifurcation

# 1. Introduction

Mathematical modeling involves utilizing mathematical methods and techniques to represent, analyze, predict, and provide insights into various real-world phenomena, particularly in the fields of ecology [1] and epidemiology [2]. Mathematical modelling connects us with several important unanswered questions which are globally concerning. Several things related to our daily life can be modelled mathematically by taking a suitable pattern. The mathematical modelling approach involves abstraction, where not all intricacies of individual processes are given, nor are all parts of the problem included.

Mathematical biology is a well-acknowledged, most exciting and expanding modern application of mathematics. The use of mathematics in biology is unavoidable and increasing day by day as biology becomes more quantitative. Research on this topic is very useful and significant as a best mathematical model shows how a process works and predicts what may follow. Ecology and epidemiology have emerged as significant areas of research in the science of mathematical biology during the post-pandemic era. Eco-epidemiology is an emerging field within mathematical biology that simultaneously addresses ecological and epidemiological issues.

Modelling in biomathematics [19] is a remarkably strong research tool for better understanding the eco-epidemiological [37] interaction between predator and prey. The ecological models will offer detailed information about the ecological framework, enabling them to function as models for prediction. At every stage of a prey-predator system, populations are under constant threat of disease. From the mathematical and eco-epidemiological viewpoints, the disease dynamics [21, 22, 23, 24] are significantly influenced by the impact on infection and invasion progression of one population in comparison to another. As time went on, Lotka [5] and Volterra [6] initially constructed two distinct models that took into account two populations and then examined the dynamical behaviour of the model system. Many researchers [27, 31] are exploring the relevant conditions, situations and impact of various epidemic diseases on prey-predator problems in the eco-epidemiological system. In a model system, predation, cannibalism, harvesting, migration, refuge and the fear effect among prey species are significant biological elements that have a significant impact in altering the dynamic behaviour.

In this twenty-first century, we are bound by many infectious, life-taking diseases like COVID, HIV, cancer, cholera, etc. Every day, we learn something new about a new disease that is circulating and spreading around the world. So we are facing those diseases without knowing their harmfulness or heredity. In [28] and [30], the authors have taken hereditary disease in the prey species. In their model, infected prey can grow logistically and the

newborns through infected prey remain in the infected class. In our model, we have generalized the prey-predator system and taken nonhereditary disease in the prey species. So, the newborns through infected class transfer to susceptible classes. Diseases such as HIV, cancer, and polio are not hereditary because they do not pass from parent to child. These diseases can be passed on to any child born to uninfected parents. So, in our prey-predator system, we have discussed the dynamical behavior of nonhereditary disease organisms and how they grow up, develop, and spread in the ecosystem.

Functional response is an important parameter to model interacting populations. It is characterized by the amount of prey caught by each predator per unit of time. In predator and prey interactions, the most common functional response is linear. In 1959, Holling developed three types of functional responses. In Holling type I, the functional response simply follows the law of mass-action principle. There is a linear relation between the size of prey population and the highest number of prey eaten by a predator. While in Holling type II, predator's prey consumption rate develops as prey size increases but asymptotically levels off when the rate of consumption remains constant despite the growth of prey size. In an ecological model system [25, 26], a functional response helps to describe the major parameter which is known as handling time (i.e., the time needed to attack, consume, and digest the prey).

Venturino [8] explored SI or SIS models with infection propagation across prey species. The prey and predator exhibit logistic growth, with the predator consuming only infected prey. Earlier Bairagi et al. [28], Sarwardi et. al. [29] have discussed more about interactions between susceptible and infected prey and predator. Earlier the models [20, 30] show us that the susceptible prey and infected prey grow logistically and predator consumes susceptible prey and infected prey. We introduce an eco-epidemiological prey-predator model system and examine the impact of infection rate, attack rate, and other characteristics on the behaviours of the system. In this model we have discussed that infection of any disease is not hereditary. Susceptible prey can give birth to an infected prey. So, infected prey can grow logistically as a susceptible prey.

# 2. Model Description

To develop our model, we make the following authentic assumptions:

- i. In the lack of infection and predation, the prey species expands logistically.
- ii. As infection is available, the prey population is split between two distinct categories and where: is susceptible species and is an infected species. Here and are expanding operationally at fundamental rates of and respectively.
- iii. The offspring from the population are not infected, indicating that the infection is neither genetic nor genetically transmitted, but the offspring from the infected species fall into the susceptible class (S).
- iv. Since predators cannot differentiate between infected and healthy prey, they consume both susceptible and infected prey populations at rates of ' $\alpha$ S' and ' $\beta$ I' respectively. This means we have adopted a linear functional response for predators [3], where  $\alpha$  and  $\beta$  represent the predator's per capita attack rates on susceptible and infected prey populations, respectively.
- v. Consuming equally susceptible and infected prey populations increases predator growth rate with conversion efficiency.
- vi. Every individual of the susceptible population is potentially susceptible, as are

all members of the infected subpopulation. As a result of the law of collective action, the infection grows by interaction between an infected and susceptible population, such that " is the incidence, where infectious contact rate is denoted by  $\lambda$ , i.e., the rate of infection per susceptible per infective.

vii. Let  $\mu \equiv$  death rate of I population owing to infection,  $\delta \equiv$  rate of natural death of (all being per capita rates), K  $\equiv$  environmental carrying capacity of the prey population.

The following equations serve as our eco-epidemiological model, which is based on the aforementioned presumptions:

$$\frac{dS}{dt} = (r_1 S + r_2 I) \left(1 - \frac{S+I}{K}\right) - \lambda SI - \alpha SP,$$
$$\frac{dI}{dt} = \lambda SI - \mu I - \beta IP,$$
$$\frac{dP}{dt} = \theta(\alpha SP + \beta IP) - \delta P.$$
(2.1)

Analyzing the model system requires non-negative initial conditions. We shall research the aforementioned model system for the dynamic response of the population in the following parts.

# 3. Equilibria and their Feasibility

We now determine the model system's (2.1) equilibrium states. Populations remain static when they are at an equilibrium condition. The model equations' nullclines in (2.1) are used to determine the equilibrium states:

- i. The trivial equilibrium point  $E_0$  (0,00) is indeed feasible.
- ii. The infected population free equilibrium point is  $E_1(S_1, 0, P_1)$ , where  $S_1 = \frac{\delta}{\theta \alpha}$ ,  $P_1 = \frac{r_1(\theta K \alpha \delta)}{\theta \alpha^2 K}$ .  $E_1$  is feasible if  $\underline{\theta K} \alpha > \delta$ .
- iii. The predator population free equilibrium point is  $E_2(S_2, I_2, 0)$ , where  $S_2 = \frac{\mu}{\lambda}$  and  $I_2$  is a positive root of the quadratic equation  $r_2I^2 + bI + c = 0$ , where  $b = \mu(K + \frac{r_1 + r_2}{\lambda}) r_2K$  and  $c = \frac{r_1\mu}{\lambda}(\frac{\mu}{\lambda} K)$ . As  $r_2 > 0$ , a sufficient condition for unique positive root and feasibility is b > 0, c < 0.

iv. The interior equilibrium point  $E^*(S^*, I^*, P^*)$ , where  $S^* = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A}$ ,  $I^* = \frac{\delta - \theta \alpha S^*}{\theta \beta}$ ,  $P^* = \frac{\lambda S^* - \mu}{\beta}$ , A =

$$r_{1}\theta^{2}\beta(\alpha - \beta),$$
  

$$B = \theta(r_{1}K\theta\beta^{2} + r_{2}d\alpha + \mu\alpha) - (r_{1}\theta\beta\delta + r_{2}\theta\beta\delta + \lambda\delta + r_{2}\theta^{2}\alpha\beta K),$$
  

$$C = r_{2}\delta(K\theta\beta - \delta).$$

The interior steady state  $E^*$  is feasible if  $\frac{\mu}{\lambda} < S^* < \delta \ \theta \alpha$ .

The system parameters determine whether or not the equilibrium points are feasible. The parameters spread of the infection of the prey population( $\lambda$ ), the intrinsic growth rate of infected prey population() are critical in sustaining the stable zone.

# 4. Some Basic Results

We proposed a system for an eco-epidemiological model. We shall examine the dynamic characteristics of the system. Here, we go through some fundamental results for the eco-epidemiological model system (2.1).

#### 4.1 Existence and Positive Invariance

Let E =, the system (2.1) may be written by  $\ddot{E} = g(E) \cdot Now,$   $g_1 = (r_1 S + r_2 I) \left(1 - \frac{S + I}{K}\right) - \lambda SI - \alpha SP'$  $g_2 = \lambda SI - \mu I - \beta IP,$ 

$$g_3 = \theta (\alpha SP + \beta IP) - \delta P$$
. The vector

function g is clearly smooth with respect to the variables (S,I,P) in the positive octant  $\Omega^0 = \{(S,I,P) : S \ge 0, I \ge 0, P \ge 0\}$ . Consequently, the local existence and uniqueness of the solution to the system (2.1) are ensured.

#### 4.2 Boundedness

Boundedness signifies that any system is consistent in biological order. Unbounded population size is a sign of population extinction in ecology. In order to examine an eco-epidemiological system, one must ensure that the total population of the system consistently stays in a certain range. The system's boundedness is proved by the ensuing theorem. Theorem 3.1 For specific non-negative initial conditions, all of the system's solutions (2.1) are uniformly bounded in the region B, B = and  $0 \le S + I + \frac{1}{\theta}P \le \frac{(r+\eta)K}{\eta} + \dot{\mathbf{o}}$ , for any  $\epsilon > 0$ },

where  $r = max\{r_1, r_2\}$ .

Proof: Let us consider a solution S(t), I(t) and P(t) containing non-negative initial condition

(S(0), I(0), P(0)). Also, let a function be such

that 
$$X(t) = S(t) + I(t) + \frac{1}{\theta}P(t)$$
. Now,  
 $\frac{dX}{dt} + \eta X = (r_1 S + r_2 I) \left(1 - \frac{S + I}{K}\right) - \mu I \frac{-\delta - \eta}{\theta}P + \eta S + \eta I$ 

Let  $r = max\{r_1, r_2\}$  and  $\delta > \eta$  and also, we

have,  $0 \le S + I \le K$ , then the above expression becomes

$$\frac{dX}{dt} + \eta X \le \left(S + I\right) \left[ r \left(1 - \frac{S + I}{K}\right) + \eta \right] - \mu I \le (r + n)$$

 $K(r+\eta).$ 

Ùsing a differential inequalities theorem [7], we arrive at

$$0 \le X(S,I,P) \le \frac{(r+\eta)K}{\eta} + X(S(0),I(0),P(0))e^{-\eta t},(3.1)$$

and for  $t \to +\infty, 0 \le X(S, I, P) \le \frac{(r+\eta)K}{\eta}$ .

As a result, all of the system's (2.1) solutions initiated at (S(0), I(0), P(0)) move into the zone B = and  $0 \le S + I + \frac{1}{\theta}P \le \frac{(r+\eta)K}{\eta} + \dot{\mathbf{o}}$ ,

for any  $\epsilon > 0$ }. Hence, every solution of the sys-

tem (2.1) is uniformly bounded. The proof is now complete.

K

#### 4.3 Basic Reproduction Number

We can simply demonstrate that

, so 
$$\lim_{t \to \infty} \sup S(t) \le$$

$$\frac{dI}{dt} = \lambda SI - \mu I - \beta IP < \lambda KI - \mu I$$

$$= \mu \left(\frac{\lambda K}{\mu} - 1\right) I.(3.2)$$

$$\lambda K \qquad dI$$

If 
$$R_0 \equiv \frac{\lambda K}{\mu} < 1, \Longrightarrow \frac{dI}{dt} < 0$$
, i.e., the disease

would not spread.

This outcome is connected to a threshold phenomenon that is comparable in epidemic theory [4, 9,10]. According to the latter, an infection can spread within a population if the basic reproduction number  $R_0 > 1$ . And if  $R_0 < 1$ , then eventually the infection will disappear.

## 5. Stability Analysis

We study the system's stability behaviour. This portion examines the behaviour of local and global stability at the model system's (2.1) equilibria. Infectious diseases are threatening the predator-prey system. However, the infection only affects the prey population, and it separates it into two subpopulations. The infected sub-population can grow in susceptible zones. We do a mathematical study to determine the system's stability under the given circumstances.

#### 5.1 Local Behavior

Now we investigate the model system's (2.1) local stability around all the feasible equilibria. We wish to investigate the system's behavior in the near values of the equilibria. We obtain the corresponding variational or Jacobian matrix J by linearizing the model equations for the equilibria. The system is locally asymptotically stable [11] about E if all the zeros of the characteristic equation of the matrix J around any equilibrium point E have a negative real portion. The Jacobian matrix at E is provided by

$$J(E) = \int_{\substack{r_1(1-\frac{2S}{K})-(r_1+r_2)\frac{J}{K}-\lambda I-\alpha P \\ \lambda I \\ \theta \alpha P \\ \theta \beta P \\$$

Now,  $det(J(E) - xG_3) = 0$  is the characteristic equation of J(E) in x, where  $G_3$  denotes the third order identity matrix.

# 5.2 Local stability analysis for the equilibrium $E_0$

The Jacobian matrix's eigenvalues at  $E_0$  are easily verified to be  $r_1, -\mu, -\delta$ . Since  $r_1 > 0$ , the system becomes unstable at the trivial equilibrium point. Additionally, in the direction perpendicular to the IP-plane, the trivial equilibrium point is an unstable hyperbolic saddle point.

# 5.3 Local stability analysis for the equilibrium $E_1$

Theorem 4.1. (i) The above system (2.1) exhibits locally asymptotically stability near the boundary equilibrium point  $E_1$  if the conditions (a)

 $\lambda\delta < \mu\theta\alpha$  and (b)  $\theta K\alpha > \delta$  hold.

Proof: The Jacobian matrix  $J_1$  at  $E_1$  is given by  $J_1 = (a_{ij}), i, j = 1, 2, 3$ . The following are the entries:

$$a_{11} = -\frac{r_1\delta}{\theta\alpha K}, a_{12} = r_2 - (\frac{r_1 + r_2}{K} + \lambda)\frac{\delta}{\theta\alpha}, a_{13} = -\frac{\delta}{\theta},$$
  

$$a_{21} = 0, a_{22} = \frac{1}{\theta\alpha^2 K} [\alpha K(\lambda\delta - \mu\theta\alpha) + \beta r_1(\delta - \theta\alpha K)], a_{23} = 0$$
  

$$a_{31} = r_1(\theta - \frac{\delta}{\alpha K}), a_{32} = \frac{r_1\beta}{\alpha}(\theta - \frac{\delta}{\alpha K}), a_{33} = 0$$

It is clear from the conditions  $a_{22} < 0$  and obviously  $a_{11} < 0$ ,  $a_{13} \langle 0, a_{31} \rangle 0$  and  $a_{32} > 0$ . Now we have

$$tr(J_{1}) = a_{11} + a_{22}, det(J_{1}) = -a_{13}a_{22}a_{31},$$
  

$$M_{1} = a_{11}a_{22} - a_{13}a_{31},$$
  

$$C_{1} = tr(J_{1})M_{1} - det(J_{1}) = a_{11}a_{22}(a_{11} + a_{22})$$
  

$$-a_{11}a_{13}a_{31}$$

It is evident that  $M_1 > 0, tr(J_1) < 0$ ,  $det(J_1) < 0$  and  $C_1 < 0$ . As a result, the jacobian matrix  $J_1$  satisfies the Routh-Hurwitz [11,19] criterion, i.e., the negative real components are present in all the characteristic roots of  $J_1$ . Thus, the model system (2.1) exhibits local asymptotic stability at  $E_1$ .

Theorem 4.2. (i) At the predator free equilibrium point  $E_2$ , the model system (2.1) exhibits locally asymptotically stability if the requirements

$$(a)r_{1}\left(1-\frac{2\mu}{\lambda K}\right)-\left(r_{1}+r_{2}\right)\frac{I_{2}}{K}-\lambda I_{2}<0,$$

$$(b)r_{2}\left(1-\frac{\mu}{\lambda K}\right)-\frac{r_{1}\mu}{\lambda K}-\frac{2r_{2}I_{2}}{K}-\mu<0 \text{ and }$$

$$(c)\frac{\delta}{\theta}>\frac{\mu\alpha}{\lambda}+\beta I_{2} \text{ hold.}$$

(ii) The equilibrium point *E*, the system (2.1) exhibits locally asymptotically stability for the requirements

$$(a)r_{1} < \frac{2r_{1}}{K}S + \left(\frac{r_{1}+r_{2}}{K}+\lambda\right)I + \alpha P$$

$$(b)\left(\frac{r_{1}+r_{2}}{K}+\lambda\right)\left(\alpha S -\beta I\right) + \left(\beta + \frac{2\alpha I}{K}-\alpha\right)r_{2}$$

$$(\alpha + \beta)P + \frac{2r_{1}S}{K},$$

$$(c)r_{2} < (r_{1}+r_{2})\frac{S}{K} + \frac{2r_{2}I_{2}}{K} + \lambda S,$$

 $(d)m_3 < m_1m_2$  hold. Where

$$m_{1} = r_{1} - \frac{2r_{1}}{K}S - \left(\frac{r_{1} + r_{2}}{K} + \lambda\right)I - \alpha P , m_{2} = ,$$
  
$$m_{3} = \theta\alpha\beta P I \left[\lambda P + r_{2} - \frac{2r_{2}I_{2}}{K} - \left(\frac{r_{1} + r_{2}}{K} + \lambda\right)S\right]$$

and J(E) is the Jacobian matrix at E.

Proof: (i) The Jacobian matrix  $J_2$  at  $E_2$  is given by  $J_2 = (b_{ij}), i, j = 1, 2, 3$ . The following are the entries:

$$b_{11} = r_1 \left( 1 - \frac{2\mu}{\lambda K} \right) - \left( r_1 + r_2 \right) \frac{I_2}{K} - \lambda I_2,$$
  
<sup>11</sup> <sup>13</sup> <sup>31</sup>  
 $b_{12} = r_2 \left( 1 - \frac{\mu}{\lambda K} \right) - \frac{r_1 \mu}{\lambda K} - \frac{2r_2 I_2}{K} - \mu,$   
 $b_{13} = -\frac{\mu \alpha}{\lambda}, \ b_{21} = \lambda I_2, \ b_{22} = 0, \ b_{23} = \beta I_2$ 

$$b_{31} = 0, \ b_{32} = 0, \ b_{33} = \theta \left( \frac{\mu \alpha}{\lambda} + \beta I_2 \right) - \delta$$

It is clear from the conditions  $b_{11} < 0, b_{12} < 0, b_{33} < 0$ and obviously  $b_{13} \langle 0, b_{21} \rangle 0$  and  $b_{23} > 0$ . Now we have  $tr(J_2) = b_{11} + b_{33}, det(J_2) = -b_{12}b_{21}b_{33},$  $M_2 = -b_{12}b_{21} + b_{11}b_{33}$  $C_{2} = tr(J_{2})M_{2} - det(J_{2}) = b_{11}^{2}b_{33} + b_{11}b_{33}^{2} - b_{11}b_{12}b_{21}.$ It evident that is

 $M_2 > 0, tr(J_2) < 0, det(J_2) < 0$  and  $C_2 < 0$ . As a result, the jacobian matrix  $J_2$  satisfies the Routh-Hurwitz criterion, i.e., the negative real components are present in all the characteristic roots of  $J_2$ . Hence, the system is locally asymptotically stable at  $E_2$ .

(ii) The Jacobian matrix at E is J =, where

$$c_{11} = r_1 - \frac{2r_1}{K}S^* - \left(\frac{r_1 + r_2}{K} + \lambda\right)I^* - \alpha P^*,$$
  

$$c_{12} = r_2 - \left(\frac{r_1 + r_2}{K}\right)S^* - \frac{2r_2}{K}I^* - \lambda S^*,$$
  

$$c_{13} = -\alpha S^* < 0, \ c_{21} = \lambda I^* > 0, \ c_{22} = 0,$$
  

$$c_{23} = -\beta I^* < 0, \ c_{31} = \theta \alpha P^* > 0,$$
  

$$c_{32} = \theta \beta P^* > 0, \ c_{33} = 0.$$
(4.1)

The following is the characteristic equation of J,

$$x^{3} - tr(J)x^{2} + tr(adj(J))x - det(J) = 0.(4.2)$$

The conditions on the theorem statement show that tr(J) < 0,  $det(J) \langle 0, M \rangle 0$  and  $C_3 = tr(J) \cdot tr(adj(J)) - det(J) < 0$ . By Routh-Hurwitz criterion, the proof is completed.

#### 5.4 Behavior of Global Stability

We shall now investigate our model system's (2.1) global stability at *E* using the linearized system shown below.

$$\frac{dS_1}{dt} = c_{11}S_1 + c_{12}I_1 + c_{13}P_1 + H_1$$
$$\frac{dI_1}{dt} = c_{21}S_1 + c_{23}P_1 + H_2$$
$$\frac{dP_1}{dt} = c_{31}S_1 + c_{32}I_1 + H_3$$
(4.3)

where  $H_1, H_2, H_3$  are higher order terms and  $S_1 = S - S$ ,  $I_1 = I - I$ ,  $P_1 = P - P$ . Now, we define  $L = \frac{1}{2}S_1^2 + \frac{l_1}{2}I_1^2 + \frac{l_2}{2}P_1^2$  (4.4) where  $l_1, l_2 > 0$  are to be chosen later. Clearly  $L > 0, \forall (S_1, I_1, P_1) \neq (0, 0, 0)$  and L(0, 0, 0) = 0. Therefore L will be a Lypunov function for the dynamical system (4.3) if  $\frac{dL}{dt} \le 0$  for all possible  $(S_1, I_1, P_1)$ . Now,

$$\frac{dL}{dt} \le c_{11}S_{1}^{2} + (c_{12} + l_1c_{21})S_1I_1 + (l_1c_{23} + l_2c_{32})$$
$$I_1P_1 + (c_{13} + l_2c_{31})S_1P_1 + H_4$$
(4.5)

where the higher order terms are indicated by  $H_4$ . Applying the inequality

$$xy \le \frac{1}{2}\varepsilon_i x^2 + \frac{1}{2\varepsilon_i} y^2$$

where  $x, y, \dot{o} \ge 0$ . Now we get,

$$\frac{dL}{dt} \leq [c_{11} + \frac{1}{2\varepsilon_1}(c_{12} + l_1c_{21}) + \frac{1}{2}\varepsilon_3(c_{13} + l_2c_{31})]S_1^2 + \left[\frac{1}{2}\varepsilon_1(c_{12} + l_1c_{21}) + \frac{1}{2\varepsilon_2}(l_1c_{23} + l_2c_{32})\right]I_1^2 + \left[\frac{1}{2}\varepsilon_2(l_1c_{23} + l_2c_{32}) + \frac{1}{2\varepsilon_3}(c_{13} + l_2c_{31})\right]P_1^2$$

leaving out the higher order terms. Then, if we set  $\dot{\boldsymbol{o}}_1 = \dot{\boldsymbol{o}}_2 = \dot{\boldsymbol{o}}_3 = 1$  and  $l_1 = \frac{S}{I}$ and  $l_2 = \frac{S}{P}$ , it can easily verify that  $c_{12} + l_1c_{21} = r_2 - (r_1 + r_2)\frac{S}{K} - \frac{2r_2I}{K} < 0$ ,  $c_{13} + l_2c_{31} = -\alpha(1-\theta)S < 0$ ,  $l_1c_{23} + l_2c_{32} = -\beta(1-\theta)S < 0$  if

$$r_2 < (r_1 + r_2) \frac{S}{K} + \frac{2r_2I}{K}$$
 and  $\theta < 1$ .

Consequently,  $\frac{dL}{dt} \le 0$  for the chosen  $l_1, l_2$ . According to LaSalle's theorem [12], the system is globally asymptotically stable around the interior equilibrium point E.

# 6. Hopf bifurcation at $E^*$

Here, we have discussed the instability of Hopf bifurcation at *E*.

Theorem 5.1. The dynamical system (2.1) undergoes a Hopf bifurcation at *E* if the crucial parameter  $r_2$  attains  $(r_2)_h$  in the region

 $D_{HB} = \{\lambda_h \dot{\mathbf{O}} R_+ : C_3(r_2)_h = 0, \text{ with } k_2(r_2)_h > 0$ and  $\frac{dC_3}{dr_2} \neq 0\}.$ 

Proof: The necessary and sufficient requirements for Hopf-bifurcation to happen at Eare that  $\exists$  a particular value of the parameter  $r_2 = (\text{say})$  such that  $C_3 = k_1$  with  $k_2$  and R, where  $k_1 = -tr(J(E)), k_2 = tr(adj(J(E))),$  $k_3 = -det(J(E))$  and x is determined by the characteristic equation of J as follows:

$$x^3 + k_1 x^2 + k_2 x + k_3 = 0. (5.1)$$

If  $k_1k_2 - k_3 = 0$  for a certain set of values of the system parameters, the equation (5.1) will possess a pair of roots that is purely imaginary. Now, let  $r_2 = (r_2)_h$  be such that  $k_1k_2 - k_3 = 0$  $\Rightarrow tr(J(E))tr(adj(J(E))) - det(J(E)) = 0$ , for which we get,  $c_{12}(c_{11}c_{21} + c_{23}c_{31}) + c_{13}(c_{11}c_{31} + c_{21}c_{32}) = 0$  $\Rightarrow m_1m_2 - m_3 = 0$  $\Rightarrow p_1$ . Where  $m_1, m_2$  and  $m_3$  previously defined and  $p_1, p_2$  and  $p_3$  are variables of parameters except

*r*<sub>2</sub>. We find the critical parameter as  $r_2 = (r_2)_h$ . By applying the condition,  $k_1k_2 - k_3 = 0$ , from (5.1) we can get

$$(x+k_1)(x^2+k_2)=0,$$
 (5.3)

three roots are

 $x_1 = +i\sqrt{k_2}, x_2 = -i\sqrt{k_2}, x_3 = -k_1$ . Thus, there exists a pair of purely imag-

inary eigenvalues  $\pm i \sqrt{k_2}$ . In general, for every values of x, the roots are of the form  $x_1(r_2) = \xi_1(r_2) + i\xi_2(r_2), x_2(r_2) = \xi_1(r_2)$ 

 $-i\xi_2(r_2), x_3(r_2) = -k_1(r_2)$ . Applying differentiation on (5.1) with respect to  $r_2$ , we get

$$\frac{dx}{dr_2} = -\frac{x^2 \dot{k_1} + x \dot{k_2} + \dot{k_3}}{3x^2 + 2k_1 x + k_2} \Big|_{x=i\sqrt{k_2}} ; \ \dot{k_j} = \frac{dk_j}{dr_2}$$

$$= \frac{k_3 - k_2 k_1 + i k_2 \sqrt{k_2}}{2 \left(k_2 - i k_1 \sqrt{k_2}\right)}$$
  
= 
$$\frac{\left(\dot{k_3} - k_2 \dot{k_1} + i \dot{k_2} \sqrt{k_2}\right) \left(k_2 + i k_1 \sqrt{k_2}\right)}{2 \left(k_2^2 + k_1^2 k_2\right)}$$
  
= 
$$-\frac{k_1 \dot{k_2} + k_2 \dot{k_1} - \dot{k_3}}{2 \left(k_1^2 + k_2\right)} + i \left[\frac{k_2 \dot{k_2} \sqrt{k_2} - k_1 \sqrt{k_2} \left(k_1 \dot{k_2} + k_2 \dot{k_1} - \dot{k_3}\right) + k_1^2 \sqrt{k_2} \dot{k_2}}{2 k_2 \left(k_1^2 + k_2\right)}\right]$$

$$= -\frac{\frac{dC_3}{dr_2}}{2\left(k_1^2 + k_2\right)} + i\left[\frac{\sqrt{k_2}\dot{k_2}}{2k_2} - \frac{k_1\sqrt{k_2}\frac{dC_3}{dr_2}}{2k_2\left(k_1^2 + k_2\right)}\right] (5.4)$$

Hence,

$$Re\left(\frac{dx(r_2)}{dr_2}\right)|_{r_2=(r_2)_h} = -\frac{\frac{dC_3}{dr_2}}{2(k_1^2 + k_2)} \neq$$
  
By theory [15], one can simply build the

requisite transversality condition  $\frac{dC_3}{dr_2}$ . This completes the proof.

As a result, the parameter value  $r_2 = (r_2)_h$  causes the system to bifurcate into periodic oscillation from a stable equilibrium condition.

# 7. Numerical Simulation

We previously demonstrated that the model system exhibits the locally and globally stability, and that Hopf bifurcation occurs theoretically around . Therefore, we have to check the validation of theoretical findings. So, we need some numerical justification of the system . In this section, we have performed several numerical simulations of the system using MATLAB and MAPLE standard software packages.

Now, we analyze a collection of potential parameter values: With this particular set of parameter values, the model system possesses an unique interior equilibrium point . For this set of parameter values, the model system (2.1) is locally asymptotically stable at the interior equilibrium point . Figure 3 illustrates the corresponding diagrams.

The model system parameters (= the intrinsic rate of growth of susceptible prey population), (= the intrinsic growth rate of infected prey population), (= the rate of infection of susceptible prey population) are particularly important since even a small adjustment can have a considerable influence on the system's dynamic behaviour. Because only change for the parameter, we examine that the model's system is locally asymptotically stable at the infected free equilibrium point. The related times series and phase portrait diagram are shown in Figure 1.

Also, for the similar parameter values except for , the system is locally asymptotically stable at the predator free equilibrium point . Figure 2 depicts the time series and phase diagram associated with this behavior. For global stability of interior equilibrium point we take the same parameter values except for . The time series and phase portrait of global behaviour have been displayed in Figure 4.

We notice that a Hopf bifurcation occurs in the system as the parameter passes the crucial value from left to right, i.e., based to the parameter value at, the system shows periodic behaviours. The periodic behavior of the system around is displayed here for . Figure 6 depicts the related time series and phase diagram for Hopf bifurcation. In bifurcation diagram Figure 7, we showed that every species for is stable, but after crossing the value 2.1, the system becomes unstable. So, numerically we have a supercritical Hopf bifurcation. Also we have seen a Hopf bifurcation at the predator free equilibrium point for the same parameter values except for and . The time series and phase diagram have been displayed in Figure 5.

Now, we discuss a major dynamical behaviour of the model system. We have seen that the stability changes from interior equilibrium point to predator free equilibrium point and also predator free equilibrium point to interior equilibrium point. We have noticed that for the similar parameter values except for  $\lambda$ , there exist a transcritical bifurcation from interior equilibrium point to predator free equilibrium point . When we vary the infection rate  $\lambda$  of susceptible prey, it has been discovered that, the system is locally asymptotically stable around and is unstable and when  $\lambda$  crosses the critical value, is stable but does not exist. The related phase diagram is shown in Figure 8. As a result, the parameter  $\lambda$  is crucial in controlling the dynamical behavior of our proposed model system. Again for the similar parameter values except for the intrinsic growth rate of infected prey, we observe that there exists a transcritical bifurcation from predator free equilibrium point to interior equilibrium point. When we vary the parameter , it is noticed that for <, the model system is locally asymptotically stable around but does not exist and when it crosses the critical value , the system becomes stable around and unstable around . The related phase diagram has been displayed in Figure 8. Thus, plays a crucial role in determining the system's dynamical behavior.

#### 7.1 Effect of Varying the Coefficient of Intrinsic Growth Rate of Infected Prey **r**<sub>2</sub>

In this present subsection the implications of the parameter on the system's dynamical behavior have been covered. Let us take the parameter values as and vary the value of the parameter between 0.1 to 0.52. When the value of gradually increasing from 0.1 to 0.52, we can see that the populations of susceptible prey and predators are increasing, while the population of infected prey is decreasing. These significant behaviors caused by the effects of intrinsic growth rate of infected prey are shown in Figure 9.

# 7.2 Effect of Varying the Coefficient of Rate of Infection per Susceptible $\lambda$

Another important parameter is infection rate  $\lambda$  of susceptible prey by infected prey. For the similar previous parameter values except, we vary the parameter value of  $\lambda$  between 0.165 to 0.205. When the value of  $\lambda$  gradually increases from 0.165 to 0.205, we can see that the populations of susceptible prey and predators are decreasing, while the population of infected prey is increasing. This outcome makes our model system more realistic. These effects are shown in Figure 10.





**Figure 1:** Dynamical behaviour near the infected free equilibrium point of the system with initial conditions and the parameter values. (a) Time series behavior. (b) corresponding Phase portrait.







Figure 2: Dynamical behaviour near the predator free equilibrium point of the system with initial conditions and the parameter values (a) Time series behavior. (b) Corresponding Phase portrait.



**Figure 3:** System behaviour near the interior equilibrium point of the system with initial conditions and the parameter values (a) Time series evolution. (b) Phase portrait diagram.





**Figure 4:** Global stability behaviour around the interior equilibrium point of the system with 4 set of initial conditions and the parameter values (a) Time series evolution. (b) Phase portrait diagram.







**Figure 5:** Hopf bifurcation around the predator free equilibrium point of the system with initial conditions and the parameter values (a) Time series evolution. (b) Phase portrait diagram.



**Figure 6:** Hopf Bifurcation around the interior equilibrium point of the system with initial conditions and the parameter values (a) Time series evolution. (b) Phase portrait diagram.



Figure 7: Bifurcation diagram for the interior equilibrium point of the system with initial conditions and the parameter values



Figure 8: (a) Transcritical bifurcation from to , The green dotted line indicates the range of  $\lambda$  for the stability of and the non-existence of , while the red dotted line represents the range of  $\lambda$  for the stability of and the instability of in the model system (2.1). Here we take the initial conditions as and the parameter values (b) Transcritical bifurcation from to , The green line indicates the range of for the stability of and the non-existence of , while the red line represents the range of for the stability of and the non-existence of , while the red line represents the range of for the stability of the model system . In both cases, we have taken the initial conditions as and the parameter values



(c)

**Figure 9:** The time series solution of the model system for the parametric values and varying the intrinsic growth rate of infected prey. (a)Susceptible prey. (b)Infected Prey. (c) Predator.



(c)

**Figure 10:** The time series solution of the model system for the parametric values and varying the intrinsic growth rate of infected prey  $\lambda$ . (a) Susceptible prey. (b) Infected Prey. (c) Predator.

# 8 Discussion and Conclusion

This study presents an eco-epidemiological model on the basis of growth infected prey suggested by Bairagi et al. This study is the first investigation of an eco-epidemiological system in which infected prey have the ability to breed or reproduce in the area inhabited by susceptible prey, with a positive intrinsic expansion rate that follows a logistic pattern. Typically, researchers have exclusively examined eco-epidemiological systems to consider that the infective population grows logistically in the infected prey zone. However, the breeding of new prey in susceptible populations is a biological event. Our study involves the division of the susceptible prey population into two subpopulations where susceptible and infected prey grow together . We analyze how disease affects the system in the generalized model.

The system which we have developed is a rectification of earlier research. The implementation of the corrected system will result in impacts that may be applicable to particular sorts of models in both the present and future. We mostly want to discuss the diseases which are non-hereditary like HIV, Cancer etc. Many of those types of disease are expanding worldwide among humans and animals. So, spreading of not hereditary diseases plays a crucial role in the evolution of our ecosystem.

In this eco-epidemiological dynamical system, crucial circumstances occur when the disease extinction condition becomes unstable due to a slight alteration in the intrinsic growth rate of the infected prey population parameter. This is the experience of Hopf bifurcation, which results in the periodic presence of positive equilibria. Basically, the direction of Hopfbifurcation determines whether or not these bifurcating equilibria are stable. In some cases, when attached to the ecological population, the dynamics of an epidemiological population take on a chaotic nature. This type of dynamical behaviour may be enhanced by the presence of epidemic disease in an ecological system. Here, we don't look for chaotic behaviours in the system but one can go for it in future.

We have proposed and verified a number of dynamical phenomena about uniform boundedness, threshold condition for local, global stability and Hopf bifurcation of the system around several equilibria. We qualitatively determine the parametric areas for the existence of the solution, the feasibility of a number of equilibria, and their dynamics. The model system is well-behaved because of its boundedness and the presence of positive solutions. The coexisting population of infected and predators means that the infected prey is more susceptible to predation and the predator benefits from the infected prey. We observe that the intrinsic growth rates of susceptible prey, infected prey and the disease infection rate play a sensible role for persisting three populations for the long run. Because suitable change to these parameters lead to extinction of either the susceptible or the infected prey population.

One of the main objectives in studying an eco-epidemiological model is to identify techniques and strategies to prevent infections. An intriguing scenario arises when there is no infection present, meaning the system comprises only susceptible prey and their predators. In our research, we discovered that the infection rate of susceptible prey by infected prey plays a crucial role in the system's dynamics at the infection-free point. Even a minor alteration to this parameter can destabilize a previously stable system around the disease-free equilibrium. Additionally, an increased intrinsic growth rate of infected prey leads to periodic oscillations at the interior equilibrium state, resulting from a Hopf bifurcation.

This system is specific. So, any new system may be created and researched using the results of the current study. The findings of this study are generic types that may be used to any specific classes of a model system that adheres to the same ecological presumptions that we took into consideration.

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# 79. Mathematical modeling and diffusion-driven induced pattern formation in a prey-predator system in presence of diffusion

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#### Abstract

This paper deals with a simple prey-predator system in presence of self as well as cross-diffusion. We have done bifurcation analysis in a two-parametric space. The diagram informs parameter selection for pattern generation and control. The variation in the death rate of the predator yields transitions from pure Hopf to Hopf-Turing, Turing, and stable patterns. Within the Turing region, we examine the impact of parameter variation, particularly the death rate parameter, while holding other factors constant. Our analysis underscores the role of predator death rates and prey growth rates in the spatial predator-prey model. Additionally, we have investigated pattern formation with respect to the cross-diffusion parameter as a key driver of Turing pattern formation. Further parameter exploration promises insights into pattern formation dynamics.

Keywords: Prey-Predator, Holling type II, Cross diffusion, Dispersion, Turing pattern.

# 1. Introduction

In our daily lives, the pervasive influence of mathematics is undeniable, shaping phenomena from the macroscopic to the microscopic. The mathematical modeling tool empowers us to articulate complex real-world processes in precise mathematical terms, transcending disciplinary boundaries. This paper delves into the profound intersection of mathematical modeling and ecological systems, exploring how diffusion-driven mechanisms catalyze the formation of intricate patterns in nature. Within the realm of mathematical biology, we embark on a journey where mathematical models serve as invaluable assets in understanding the dynamics of biological systems. Our focus extends to the pressing issue of disease spread, exemplified by

the COVID-19 pandemic, where these models offer critical insights into disease transmission, guiding informed policy decisions that save lives. Meanwhile, mathematical ecology unveils the intricate tapestry of species interactions, biodiversity, and population dynamics through mathematical models, particularly emphasizing the predator-prey dynamics underpinning ecological relationships (Lotka, A. J 1925, Volterra, V 1926, Turing, A. M 1952, Segel, L., and Jackson, J. L 1972 and Kerner, E. 1959).

Patterns in the natural world have long captivated human imagination, whether in the mesmerizing morphological shapes of living organisms or the meandering courses of rivers. Pattern formation, an emerging frontier in scientific exploration, is a testament to

human curiosity. Inspired by the pioneering work of Alan Turing in "The Chemical Basis of Morphogenesis," we delve into the elegant concept of pattern formation through diffusion-driven instability. This mechanism, founded on the movement of particles driven by concentration gradients, transcends temporal and spatial boundaries, finding application in domains as diverse as chemical reactions, astrophysics, hydrodynamics, and economics (Shigesada, N., Kawasaki, K., and Teramoto, E. 1979, Ghorai, S. and Poria S. 2016 and Bairagi, N. 2021). The profound concept of Turing instability forms the cornerstone of our investigation into pattern formation, offering a key to unlocking the enigmatic origins of structured spatial patterns. In this context, a reaction-diffusion system necessitates the presence of multiple reactive species with significantly distinct diffusion rates to give rise to these intricate patterns. The ripple effects of Turing's visionary ideas reverberate across various scientific disciplines, providing valuable tools for understanding and modeling spatiotemporal patterns.

Ecological systems, with their complex interdependencies, provide fertile ground for exploring the broader implications of diffusion. While diffusion is commonly associated with molecular-level processes, it manifests on a macroscopic scale within ecological contexts. Species, motivated by factors ranging from predator-prey interactions to climate and resource limitations, undergo ecological diffusion, resulting in the dispersion of population densities. This ecological diffusion, far from being a passive phenomenon, often assumes the role of a stabilizing force, influencing the dynamics of mixed populations and resource utilization.

In this present investigation, we delve into the intricacies of mathematical modeling and diffusion's profound impact on pattern formation in ecological systems. Through empirical exploration and mathematical rigor, we unravel the mysteries of nature's intricate patterns, shedding light on the underlying mechanisms that govern our natural world.

## 2. Mathematical Formulation

Let us consider a predator-prey system where the population density of prey and predator at time t are n(t) and p(t), respectively.

$$\frac{dn}{dt} = f(n, p),$$

$$\frac{dp}{dt} = g(n, p).$$
(1)

In the presence of diffusion of species, the model (1) takes the following form

$$\frac{\partial n}{\partial t} = f(n, p) + D_{11} \nabla^2 n + D_{12} \nabla^2 n$$
$$\frac{\partial p}{\partial t} = g(n, p) + D_{21} \nabla^2 n + D_{22} \nabla^2 p \qquad (2)$$

where  $D_{11}, D_{22}$  are self-diffusion coefficients for prey and predator, respectively, and are always positive because they move from higher to lower concentration and  $D_{12}, D_{21}$  are the cross-diffusion coefficients.  $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}$ is the Laplacian operator. We investigate the model (2) under the following positive initial conditions

$$n(\vec{x}, 0) > 0, \ p(\vec{x}, 0) > 0, \ \vec{x} = (x, y) \in \Omega$$
  
 $\subset \mathbb{R}^2$ 
(3)

with zero-flux boundary conditions

$$\frac{\partial n}{\partial v} = \frac{\partial p}{\partial v} = 0, \text{ on } \partial \Omega \times (0, t],$$
 (4)

where  $\Omega$  is the 2-D spatial domain and v is the outward unit normal vector at the boundary  $\partial \dot{U}$ . The equation (4) implies that species in  $\Omega$ cannot leave outside of the domain  $\Omega$  and the species outside cannot enter the domain  $\Omega$ .

#### 2.1. Local System Analysis

Without loss of generality, let  $E^* \equiv (n^*, p^*)$  be the positive equilibrium point of the system without diffusion. The characteristic equation is given by  $\lambda^2 - \operatorname{tr} (J_0)\lambda + \Delta_0 = 0$  where  $\operatorname{tr} (J_0) = a_{11} + a_{22}, \Delta_0 = a_{11}a_{22} - a_{12}a_{21}$ . The local system (1) will be stable if

tr 
$$(J_0) < 0$$
 and  $\Delta_0 > 0$ ,  
i.e.,  $a_{11} + a_{22} < 0$  and  $a_{11}a_{22} - a_{12}a_{21} > 0$ . (5)

$$\operatorname{tr}(J_0) = \frac{D\left[C\left(B-1\right) - BD\left(B+1\right)\right]}{C\left(C-BD\right)}, \ \Delta_0$$
$$= \frac{D}{C}\left(C-BD-D\right) \tag{11}$$

If cross diffusion coefficients are absent, the conditions  $a_{11} < 0$  and  $D_{11}a_{11} > 0$  cannot hold simultaneously. Thus, the Turing pattern cannot occur if cross-diffusions are absent in this system. On the other hand, it is observed that

If  $B \le 1$ , the local system (11) is globally asymptotically stable, and if B > 1, the local system (11) will be stable if  $D > D_H$ , where  $D_H$ is the Hopf-bifurcation parameter given by the following expression

$$\operatorname{tr}(J_0) < 0 \Rightarrow D_H < D, \left[ \text{ where, } D_H = \frac{C(B-1)}{B(B+1)} \right]$$
(12)

With a straightforward manipulation, the condition (7d) can be written as we have,

$$\frac{D[BC-C-B^{2}D-BD]}{C(C-BD)}D_{22} + \frac{D}{C}D_{21} - (C-BD-D)D_{12}$$

$$> 2\sqrt{(D_{22}D_{11} - D_{21}D_{12})\frac{D}{C}(C-BD-D)}.$$
(13)

Taking D as a bifurcation parameter, the critical parameter value for Turing bifurcation  $D_T$  can be obtained by solving equation (13).

Therefore, Turing pattern is possible in this particular predator-prey system with cross-diffusion.

### 5. Numerical Simulation

In this section, we perform a series of numerical simulations of the model (2) to understand the behavior of the dynamics of the model. The non-dimensional parameter D is the ratio of predator's death rate and prey's growth rate. An increase in this ratio implies an increase in the death of predators, and a decrease in this ratio means an increase in the birth rate of prey. The predator's death rate and the prey's growth rate are the most critical parameters in any food chain model, which is why D is considered here as a control parameter.



Figure 1: Region diagram in  $(D, D_{21})$  parametric space. The parameters are taken as  $B = 1.5, C = 0.1, D_{11} = 1, D_{12} = 1$  and  $D_{22} = 5$ .

First, we draw the Hopf bifurcation diagram. For this, we take  $B = 1.5, C = 0.1, D_{11} = 1$ ,  $D_{12} = 1$  and  $D_{22} = 5$ . Putting the above values in (14), we find the value of  $D_H = 0.013$  (approx). Hopf bifurcation occurs for  $D < D_H = 0.013$ .

Next, we draw the Turing curve on the same figure (Figure 1) using the Turing instability condition (19). The region above the Turing curve is Turing region. So the region on the left side of the Hopf curve and above Turing curve is Hopf-Turing region, and below is Pure Hopf region. The region on the right side of Hopf curve and above Turing curve is the Turing region, and below is stable region.

#### 5.1. Variation of Pattern Due to Changes in D

First, we wish to see how the and , (be the maximum eigenvalue of the characteristic equation) varies against the wavenumber k. We draw two separate figures taking B = 1.5, C = $0.1, D_{11} = 1, D_{12} = 1, D_{21} = 3.5$ , and  $D_{22} = 5$ .



**Figure 2:** (a) The behavior of  $\hat{A}_k$  against the wavenumber k for different values of D. (b) The behavior of  $\lambda_1(k)$  against k for different values of D. The solid line represents real part of  $\lambda_1(k)$  (maximum eigenvalue), and the dash lines are the corresponding imaginary part.



Figure 3: The upper row (a, b, c) represents the spatial distribution of the prey for D = 0.02 at time t = 100,500,5000, respectively. The lower row represents the same as that of the predator. The other parameters are fixed in Figure 2.

This shows that  $\ddot{A}_k$  will be negative only when k lies between  $k_1$  and  $k_2$  and  $\lambda_k$  will be positive only when k lies between  $k_1$  and  $k_2$  and in these cases only we will get Turing pattern.

Now, we will try to visualize the spatiotemporal pattern due to cross-diffusion using MATLAB. At first, we will see the pattern for both prey and predator for some finite time and for fixed value of D and then we will see the pattern for prey and predator after a long time and observe how they change when we change D. Here, we want to know the pattern formation due to cross-diffusion at some finite time (t = 100, 500, 5000), keeping D fixed (D = 0.02). We observe that as time increases, the prey population arranges itself in a cold spot pattern (Figure 3c), and simultaneously, the predator population arranges.

Next, we wish to find the pattern formation of prey population due to cross-diffusion after a very long time, and we will also see how the pattern changes when we change D. For D = 0.0185, we find the co-existence of both cold spot and cold stripe pattern (Figure 4 a) in the prey population, but when we decrease the value of D to 0.017, we see that the cold spot vanishes and only stripe pattern is present (Figure 4 b). Again, when we decrease the value of D to 0.015, we find that hot stripes appear with few hot spots (Figure 4 c). Further, if we decrease D to 0.0135, hot stripes disappear, and only the hot spots pattern remains (Figure 4 d). So, we observe that as we reduce the value of D the prey population pattern changes from mixed cold spot and cold stripes to complete hot spot patterns.



Figure 4: Long-time spatial distribution of prey for different values of D (a) D = 0.0185; (b) D = 0.017; (c) D = 0.015; (d) D = 0.0135. The other parameter are fixed, as like Figure 2.

Predators will show exactly opposite spatial distribution as compared to prey. So, we can also determine the spatial distribution of predators by observing prey patterns. For example, if there is a hot spot for prey species, there will be a cold spot for predators.

# 5.2. Variation of Pattern Due to Changes in the Cross-Diffusion Coefficient

In Figures 5 and 6, we have the patterns of prey population for the variation of the cross-diffusion co-efficient D = 0.015; (d) D = 0.0135. $3(D=0.02 \& D_{21} = 3.5),$ In Figure we see that the prey population arranges themselves in a cold spot pattern and Figure  $6(D = 0.02 \& D_{21} = 4, 4.5, 4.8)$ , we see that as we change  $D_{21}$  the pattern changes from cold spot to mixed cold spot and cold stripe pattern. Still, the density of prey population increases compared to the previous case. In Figure 4 c  $(D = 0.015 \& D_{21} = 3.5)$ , we see that the prey species show a hot stripe pattern with very few hot spots but as we increase  $D_{21^4}$  from 3 to 4.8 we see that the hot stripe pattern changes to mixed hot stripe and hot spot pattern and in this case also the density of prey species increases. Normally, it is assumed that when  $D_{21}$  increases, i.e., the cross-diffusion of predator into prey population increases, the predation increases, and hence, the prey population decreases. Still, here we see a

contradiction: despite the increase of  $D_{21}$  the prey density increases, which is opposite to the usual case.



Figure 5: Long-time spatial distribution of prey for different values of  $D_{21}$  (a)  $D_{21} = 3$ ; (b)  $D_{21} = 4$ ; (c)  $D_{21} = 4.5$ ; (d)  $D_{21} = 4.8$ ; D = 0.015 and the other parameters are fixed as like Figure 2.



**Figure 6:** Long-time spatial distribution of prey for different values of  $D_{21}$  (a)  $D_{21} = 4$ ; (b)  $D_{21} = 4.5$ ; (c)  $D_{21} = 4.8$ ; D = 0.02 and the other parameters are fixed as like Figure 2.

So, we see that the parameters are independent of spatial co-ordinates, but if we change the parameters, the spatial behavior changes.

### 6. Summary

We have done bifurcation analysis in  $D_{21} - D$  parametric space, and the corresponding bifurcation diagram is presented in Figure 1. The bifurcation diagram helps us to choose the parameters for obtaining suitable patterns as well as for controlling the spatiotemporal patterns. It is clear from Figure 1 that varying the parameter D only the transition from pure Hopf  $\rightarrow$  Hopf-Turing  $\rightarrow$  Turing  $\rightarrow$  stable patterns are possible. The effect of variation of D in the Turing region is presented in Figures 3 and 4. It is observed that the transition from cold spots  $\rightarrow$  mixture of cold spots and cold stripes  $\rightarrow$  cold stripes  $\rightarrow$  hot stripes  $\rightarrow$  mixture of hot spots

and hot stripes  $\rightarrow$  hot spots are possible in the Turing region with the variation of D only keeping all other parameters fixed. Our results show that the death rate of predators or the growth rate of prey can play a vital role in the spatial predator-prey model. The cross-diffusion parameter  $D_{21}$ plays a crucial role in making the Turing pattern and also for significant variations of the Turing pattern for the said model, as shown in Figures 5 and 6. One can investigate the effects of variation of other parameters in the pattern formation for further investigation. We have taken a system with logistic growth of prey and linear predator death. When the system (10) is analyzed under self-diffusion only, it fails to produce Turing pattern. But when the system is analyzed under cross-diffusion and self-diffusion, it produces a Turing pattern. So, a system with the linear death rate of predator and self-diffusion fails to make Turing pattern, while cross-diffusion has Turing pattern.

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# 80. Solute transport through porous media: A Time dependent approach

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## Abstract

Groundwater contamination is a major problem in the countries like India where most of the house hold work and the agricultural directly or indirectly depends on groundwater. In this present work authors consider that a huge number of wastes is dumped in a deep excavation in soil by industries. It is assumed that no more wastes are dumped into that excavation further. Contaminated water seeps through that soil zone of excavation and contaminates nearby soil zone as well as aquifer system. In case of heterogeneous porous media, contaminant concentration will decay at an exponential rate as distance goes. Time dependent exponentially decaying input source has been considered.

Keywords: Dispersion; Contaminant Transport; Mathematical Modelling; ADE.

# 1. Introduction

Ground water is one of the most useful resources for the most of the people of rural India. But day by day it is contaminated and become useless for daily purposes. For last few decades advection dispersion equation is used to model the contaminant concentration flow in the aquifer system.

During the past several decades a large number of analytical solutions have been developed for estimating the fate and transport of various constituent in the sub surface environment. Application of these solutions is generally limited to steady groundwater flow fields and to relatively simple initial and boundary conditions. These analytical solutions play very important role in contaminant transport studies. Analytical solutions give initial or approximate estimates of solute concentration distribution of soil and aquifer systems. Kaluarachchi and parker [1] discussed an efficient finite element method for modelling multiphase flow in groundwater contamination problem. Logan [2] presented an extension of the work of Yates [3] for solute transport in porous media with scale-dependent dispersion and periodic boundary condition. Aral and Lion [4] obtained a general analytical solution for an infinite domain aquifer, where two-dimensional solute transport equation with time-dependent dispersion coefficient was used.

In different seasons of the year the saturation of the soil is different so there is a dependency of time present. In most earlier studies homogeneous medium has been considered while modelling this kind of situation [5-7].

The dispersion co-efficient is treated as a function of the viscosity gradient, so that a larger "effective" dispersion coefficient results for adverse-mobility-ratio relationships. [8].

Contaminant transport modelling in environmental geotechnics generally is performed to evaluate the potential impact of contaminant migration on the surface environment. [9].

This type of problem has been considered earlier [10-11] but here we consider time-dependent exponentially decaying input sources usually occurred at the inlet of natural or human-made system which it is not considered by the researcher and scientists as far our knowledge. Authors are going to solve the ADE equation using Laplace Transform method and thereby validate that solution with the help of Crank-Nicholson scheme.

### 2. Mathematical Model

#### 2.1 Mathematical Formulation

Contaminant transport in isotropic homogeneous porous media is generally modeled by assuming a constant average transport velocity, linear equilibrium sorption. For a finite (of length L0) or semi-infinite medium, this problem can be formulated as:

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} - u \frac{\partial C}{\partial x}$$
(1)

Where, C(x,t) [ML<sup>-3</sup>] is the contaminant concentration, u [LT<sup>1</sup>] is the groundwater velocity or seepage velocity, D [L<sup>2</sup>T<sup>1</sup>] is the hydrodynamic dispersion coefficient, t [T] is time and x [L] is distance.

#### 2.2 Initial Condition

It is assumed that initially the groundwater is not solute free which can be due to some internal cause or effect in the aquifer [10]. Therefore, the initial condition is considered as:

$$C(x,t) = C_0; x \ge 0, t = 0$$
(2)

Where,  $C_0$  [ML<sup>-3</sup>] is the initial contaminant concentration.

#### 2.3 Inlet Boundary Condition

The input concentration at the source, where contaminants reach the groundwater, is considered as a time-dependent function [12], expressed as

$$C(x,t) = \exp(-\beta t); x = 0, t > 0$$
(3)

Where,  $\beta$  is exponential decay rate [T<sup>1</sup>] [11]

Eq.3 describe possible formulation of the inlet boundary condition at x = 0, generally referred to as first-type (or Dirichlet) boundary conditions.

While the stipulation of such, a concentration continuity at x = 0 may have an intuitive appeal, it is obtained at the cost of maintaining a solute flux continuity across the inlet position [13].

#### 2.4 Outlet Boundary Condition

Consider a unidirectional flow field containing strip solute sources whose concentrations are functions of the z coordinate, as shown schematically in Figure 1. The medium is semi-infinite in the x direction  $(0 < x < \infty)$  [14].

For a semi-infinite aquifer system, the outlet boundary condition specifies the behavior of the concentration as infinity is closer [15]. It is plausible that change in concentration with respect to distance are negligible as distance goes to infinity, thus the outlet boundary condition is:

$$\frac{\partial C}{\partial x} = 0; x \to \infty, t > 0$$
(4)

#### 2.5 Analytical Solution

Following Yang and Chen [16] authors uses Laplace transform method to solve the modelled problem. It is assumed that  $D(t) = K_1.u(t)$ [Here, K1: asymptotic

dispersivity [L] and considering, Eq.1 will be transformed into a form of,

$$\frac{\partial \mathbf{c}}{\partial T} = \mathbf{K}_1 \frac{\partial^2 \mathbf{c}}{\partial \mathbf{x}^2} - \frac{\partial \mathbf{c}}{\partial \mathbf{x}}$$
(5)

Subjected to initial and boundary conditions can be written as follows:

$$c(x,T) = C_0; T = 0; x > 0$$
 (6) 12

$$c(x,T) = exp(-\beta,T); x = 0; T > 0$$
 (7)

$$\frac{\partial \mathbf{c}}{\partial \mathbf{x}} = 0 \; ; \; \mathbf{x} \to \infty \tag{8}$$

By using Laplace transformation, we can get solution of Eq. 5 with initial conditions Eq. 6 and boundary conditions Eq. 7:

$$\begin{split} C(x,t) &= [C_0.\exp\left(\frac{t}{4K_1} - \frac{x}{2K_1}\right) - \frac{C_0}{2} \left\{ \exp\left(\frac{t}{4K_1} - \frac{x}{2\sqrt{K_1}}\right) \cdot \operatorname{erfc}\left(\frac{x}{2\sqrt{tK_1}} - \frac{\sqrt{t}}{2\sqrt{K_1}}\right) + \exp\left(\frac{t}{4K_1} + \frac{x}{2\sqrt{K_1}}\right) \cdot \operatorname{erfc}\left(\frac{x}{2\sqrt{tK_1}} + \frac{\sqrt{t}}{2\sqrt{K_1}}\right) \right\} + \frac{1}{2} \left\{ \exp\left(t, \left(\frac{1}{4K_1} - \beta\right) - x, \frac{\sqrt{1-4\beta K_1}}{2\sqrt{K_1}}\right) \cdot \operatorname{erfc}\left(\frac{x}{2\sqrt{tK_1}} - \frac{\sqrt{t(1-4\beta K_1)}}{2\sqrt{K_1}}\right) \right\} + \exp\left(t, \left(\frac{1}{4K_1} - \beta\right) + x, \frac{\sqrt{1-4\beta K_1}}{2\sqrt{K_1}}\right) \cdot \operatorname{erfc}\left(\frac{x}{2\sqrt{tK_1}} + \frac{\sqrt{t(1-4\beta K_1)}}{2\sqrt{K_1}}\right) \right\} ] \end{split}$$

# 3. Result and Discussion

Validation of analytical solution by numerical solution:

We have done modelling of contaminant concentration in groundwater in Analytical method (Laplace Transform) and verified this result by Numerical method (Crank Nicholson Method using Thomas Algorithm). This result is plotted follows. We get exact result Analytically. And some error is being generated in the solution for computing the result numerically. This error can be minimized. Figure 1, Validation of analytical solution by numerical solution.



Figure 1: Validation of analytical solution by numerical solution

Concentration variation with respect to space for a fixed time is shown in figure 2.

Contaminant concentration is decreasing up to a distance of x = 4 m; after that point concentration is in steady state up to a distance of x = 10 m from the source.



Figure 2: Concentration variation with respect to space for a fixed time.

Concentration variation with respect to time at a fixed Distance, which is shown in figure 3 and figure 4:

- 1. Contaminant concentration is almost in steady condition up to a distance of 2m from the source than decreasing steeply with distance increases from the source when  $C_0 = 1$ .
- 2. Contaminant concentration is increasing steeply with distance increases from the source when  $C_0 = 0.099$ .



Figure 3: Concentration variation with respect to time at a fixed Distance.



Figure 4: Concentration variation with respect to time at a fixed Distance.

Concentration variation with respect to Dispersivity, which is shown in figure 5 and figure 6:

1. Peak point of contaminant concentration decreases up to K1 = 5 and will be steady.

- 2. Peak point of contaminant concentration decrement continues till K1=10 but here it becomes unsteady.
- 3. Peak point of contaminant concentration increases up to K1 = 30.
- 4. For K1 = 41.825, Contaminant concentration increases up to distance x = 2 m from the source and become unsteady after that point.
- 5. After K1=41.825, Contaminant concentration will be negative which is not practicable in real sense.



Figure 5: Concentration variation with respect to Dispersivity.



Figure 6: Concentration variation with respect to Dispersivity.

# 4. Conclusion

From the results shown above which we have get by analytical and numerical solution, we can conclude that:

1. With the increase in distance from source, contaminant concentration at a fixed time decreases up to certain distance and finally attends a state from where with the change in distance concentration does not change, i.e., it may be used as drinking water after application of some treatments.

2. With the increase in dispersivity, contaminant concentration increases and after a certain distance from source, it will become unsteady and after that with increasing the value of dispersivity, contaminant concentration will negative, which is not practicable.

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# 81. An ideal technique for solving linear and non-linear Goursat problems

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### Abstract

In this article, Differential Transform Method (DTM) is considered as an emerging, effective and easily calculative method for solving various complex problems. we applied this constructive method to solve linear and non-linear hyperbolic partial differential equation namely Goursat problem. To validate the accuracy and applicability of the method, some useful examples have been solved. The accuracy level of the obtained results expose the acceptability of this method over existing numerical methods.

Keywords: Differential Transform Method (DTM), Goursat's problem

# 1. Introduction

Goursat problem is a hyperbolic partial differential equation or a second order hyperbolic system which deals with two independent variables with given values on two characteristic curves originating from the same point.

The standard form of the Goursat problem with initial conditions is

$$\frac{\partial^2 u}{\partial x \partial t} = f\left(x, t, u, \frac{\partial u}{\partial x}, \frac{\partial u}{\partial t}\right), 0 \le x \le a, 0 \le t \le b.$$

$$u(x, 0) = g(x), \quad u(0, t) = h(t),$$

$$u(0, 0) = g(0) = h(0)$$
(1)

Several mathematicians have been examined Goursat equation by using various numerical methods such as Runge-Kutta Method which was used by R. H. Moore in 1961. After few years in 2001 M. J. Jang et al. introduced Two-Dimensional Differential Transform Method for parabolic, hyperbolic and elliptic type partial differential equations. Variational Iteration Method (VIM) used by Abdul-Majid Wazwa in 2007. In 2010 H. Taghvafard and G. H. Erjace alo used DTM for solving linear and non-linear partial differential equations. K. Gou and B. Sun in 2011 have developed an algorithm for solving the Goursat equations mainly based on Runga-Kutta method and Trapezoidal formula. Adomian Decomposition Method (ADM) used by R. F. Deraman et al. in 2013. Also a new scheme Newton-Cotes integration formula was introduced by R. F. Deraman in 2014 for solving Goursat partial differential equations. Finite Difference Method (FDM) used by P. K. Pandey in 2014. In 2019 A. Al-Fayadh and D. S. Faraj introduced Laplace substitution-variational iteration method for solving Goursat problems. Recently in 2021 C. Salvi et al. has been increased an interest in the development of Kernel methods for learning with sequential data to solve Goursat equation easily. In 2022 T. Naseem introduced a novel technique the reduced differential transform (RDT) and Adomian decomposition (AD) techniques for solving Goursat partial differential equations in the linear and non-linear regime.

In this paper, we represent the applicability and reliability of Two-dimensional Differential Transform Method (DTM) on linear and non-linear Goursat problem. The differential transform is a numerical method for solving differential equations. By using this method different types of partial differential equations are solved, which demonstrates the feasibility in solving partial differential equations. Onedimensional Differential Transform Method (DTM) was first introduced by J. K. Zhou in 1986 and using this method solved both linear and non-linear initial value problems in electric circuit analysis. It has been also used in various fields of physics and mathematical problems. After some time in 1999 based on this methodology, Chen and Ho developed the two-dimensional Differential Transform Method (DTM) for solving the ordinary differential equations, partial differential equations and integral equations. In this study we get the unique result which was validated by solving four problems.

# 2. Two-dimensional Differential Transform Method

The differential transformation of the function u(x, t) for m-th derivative with respect to x and n-th derivative with respect t is defined as

$$U(m,n) = \frac{1}{m!n!} \left[ \frac{\partial^{m+n} u(x,t)}{\partial x^m \partial t^n} \right] x = x_0, t = t_0 \quad (2)$$

and inverse differential transformation of U(m, n) is defined as

$$u(x,t) = \sum_{m=0}^{\infty} \sum_{n=0}^{\infty} \frac{1}{m!n!} \left[ \frac{\partial^{m+n} U(x,t)}{\partial x^m \partial t^n} \right] x^m t^n \qquad (3)$$

**Properties of DTM:** Some useful properties of DTM are given here,

Property 1:  
If 
$$(x,t) = u(x,t) \pm v(x,t)$$
, then  
 $W(m,n) = U(m,n) \pm V(m,n)$ , where  
W (m, n), U (m, n) and V (m, n) are t

W (m, n), U (m, n) and V (m, n) are the Twodimensional differential transforms of the functions w(x, t), u(x, t) and v(x, t) in (0,0).

### Property 2:

If 
$$w(x,t) = au(x,t)$$
, then  $W(m,n) = aU(m,n)$ 

**Property 3:** 

If 
$$w(x,t) = u(x,t)v(x,t)$$
, then

$$W(m,n) = \sum_{k=0}^{m} \sum_{l=0}^{m} U(k,n-l)V(m-k,l)$$

Property 4:

If 
$$w(x,t) = \frac{\partial^{r+s}u(x,t)}{\partial x^r \partial t^s}$$
, then  
 $W(m,n) = \frac{(m+r)!(n+s)!}{m!n!}U(m+r,n+s)$ 

**Property 5:** 

If 
$$w(x,t) = x^k t^h$$
, then  
 $W(m,n) = \delta(m-k, n-h)$   
 $= \begin{cases} 1 & \text{if } m = k, n = h \\ 0 & \text{elsewhere} \end{cases}$ 

Property 6:

If 
$$(x,t) = x^k e^{at}$$
, then  $W(m,n) = \delta(m-k) \frac{a^n}{n!}$ 

Property 7:

If 
$$w(x,t) = e^{au(x,t)}$$
, then  

$$W(m,n) = \begin{cases} e^{aU(0,0)} , & m = n = 0 \\ a \sum_{k=0}^{m-1} \sum_{l=0}^{n} \frac{m-k}{m} U(m-k,l) V(k,n-l), n \ge 1 \\ a \sum_{k=0}^{m} \sum_{l=0}^{n-i} \frac{n-l}{n} U(k,n-l) V(m-k,l), n \ge 1 \end{cases}$$

**Method of solution:** We apply Two-dimensional Differential Transform Method (DTM) to the Goursat problem of hyperbolic partial differential equation

(4)

$$DT\left[\frac{\partial^2 u}{\partial x \partial t}\right] = DT\left[f\left(x, t, u, \frac{\partial u}{\partial x}, \frac{\partial u}{\partial t}\right)\right]$$
  
i.e.  $(m+1)(n+1)U(m+1, n+1) =$   
 $(m+1)(n+1)U(m+1, n+1)$ 

# 3. Application of Goursat Problem

In this part to observe the accuracy and applicability of DTM we select the linear homogeneous, linear inhomogeneous and non-linear Goursat problems.

# 3.1 The Linear Homogeneous Goursat Problem

Firstly we consider the linear homogeneous problem

$$\frac{\partial^2 u}{\partial x \partial t} = f(u)$$

$$u(x,0) = g(x), u(0,t) = h(t)$$

$$u(0,0) = g(0) = h(0)$$
(5)

Here f(u) is a linear function of u.

**Example 1:** The linear homogeneous Goursat problem is

$$\frac{\partial^2 u}{\partial x \partial t} = u,$$

$$u(x,0) = e^x, \quad u(0,t) = e^t, \quad u(0,0) = 1$$
(1a)

Using the Differential Transform to the equation 1(a) and 1(b) and using the property we

tion 1(a) and 1(b) and using the property we get,

$$DT\left(\frac{\partial^2 u}{\partial x \partial t}\right) = DT(u)$$

$$DT u(x,0) = DT e^x, DT u(o,t)$$

$$DT e^t, DT u(0,0) = DT(1)$$
i.e.  $(m+1)(n+1)U(m+1,n+1) = U(m,n)$ 

$$U(m,0) = \frac{1}{m!}, U(0,n) = \frac{1}{n!}, U(0,0) = 1$$

Using the results we get,

$$U(1,0) = 1, \qquad U(2,0) = \frac{1}{2!},$$
  

$$U(2,0) = \frac{1}{2!},$$
  

$$U(0,1) = 1, \qquad U(0,2) = \frac{1}{2!},$$
  

$$U(0,2) = \frac{1}{2!},$$
  

$$U(1,1) = 1, \qquad U(1,2) = \frac{1}{2!},$$
  

$$U(1,2) = \frac{1}{2!},$$
  

$$U(2,1) = \frac{1}{2!}, \qquad U(2,2) = \frac{1}{2!2!},$$
  

$$U(2,3) = \frac{1}{2!3!},$$

Proceeding in this way we get the generalized

value of  $U(m,n) = \frac{1}{m!n!}$ Substituting all the results we get the result

$$u(x,t) = e^{x}e^{t} = e^{x+t} \qquad 1(c)$$

This result coincides with the results getting by various methods.

Example 2: The homogeneous Goursat problem

$$\frac{\partial^2 u}{\partial x \partial t} = -2u,$$
  
$$u(x,0) = e^x, \quad u(0,t) = e^{-2t}, \quad u(0,0) = 1$$

Using the Differential Transform to the equation 2(a) and 2(b) and using the property we get,

$$DT\left(\frac{\partial^2 u}{\partial x \partial t}\right) = DT(-2u)$$
$$DT u(x,0) = DT e^x, DT u(o,t) =$$
$$DT e^{-2t}, DT u(0,0) = DT(1)$$
i.e.  $(m+1)(n+1)U(m+1,n+1) = -2U(m,n)$ 

$$U(m,0) = \frac{1}{m!}, \ U(0,n) = \frac{(-2)^n}{n!}, \ U(0,0) = 1$$

Using the results we get,

$$U(1,0) = 1, \qquad U(2,0) = \frac{1}{2!}, \qquad U(3,0) = \frac{1}{3!}$$
$$U(0,1) = \frac{-2}{1!}, \qquad U(0,2) = \frac{(-2)^2}{2!}, \qquad U(0,3) = \frac{(-2)^3}{3!}$$

$$U(1,1) = \frac{-2}{1!}, \qquad U(1,2) = \frac{(-2)^2}{2!}, \qquad U(1,3) = \frac{(-2)^3}{3!}$$
$$U(2,1) = \frac{-2}{2!}, \qquad U(2,2) = \frac{(-2)^2}{2!2!},$$
$$U(2,3) = \frac{(-2)^3}{2!3!},$$

Proce in this way we get the generalized value of Using the results we get,

$$U(m,n) = \frac{\left(-2\right)^n}{m!n!}$$

Substituting all the results we get the result

$$u(x,t) = e^{x}e^{-2t} = e^{x-2t}$$
 2(c)

This result coincides with the results getting by various methods.

# 4. The Linear Inhomogeneous **Goursat Problem**

Now we consider the linear inhomogeneous problem

$$\frac{\partial^2 u}{\partial x \partial t} = f(u) + \varphi(x,t)$$
(6)  
$$u(x,0) = g(x), u(0,t) = h(t)$$
  
$$u(0,0) = g(0) = h(0)$$

Here f(u) is a linear function of u.

Example 3: The linear inhomogeneous Goursat problem is

$$\frac{\partial^2 u}{\partial x \partial t} = u - t \qquad \qquad 3(a)$$

$$u(x,0) = e^{x}, \quad u(0,t) = t + e^{t}, \quad u(0,0) = 1 \quad 3(b)$$

Using the Differential Transform to the equation 3(a) and 3(b) and using the property we get,

$$DT\left(\frac{\partial^2 u}{\partial x \partial t}\right) = DT(u-t)$$

$$DTu(x,0) = DTe^x, DTu(o,t) = 1$$

$$DT(t+e^t), DTu(0,0) = DT(1)$$
i.e.  $(m+1)(n+1)U(m+1,n+1) = 1$ 

$$U(m,n) - \delta(m,n-1)$$

$$U(m,0) = \frac{1}{m!}, U(0,n) = \frac{1}{n!} + \delta(n-1),$$

$$U(0,0) = 1$$

$$U(1,0) = 1, \qquad U(2,0) = \frac{1}{2!}, \qquad U(3,0) = \frac{1}{3!}$$
$$U(0,1) = \frac{1}{1!} + 1, \qquad U(0,2) = \frac{1}{2!}, U(0,3) = \frac{1}{3!}$$
$$U(1,1) = \frac{1}{1!}, \qquad U(1,2) = \frac{1}{2!}, U(1,3) = \frac{1}{3!}$$
$$U(2,1) = \frac{-1}{2!}, \qquad U(2,2) = \frac{1}{2!2!},$$
$$U(2,3) = \frac{1}{2!3!},$$

1

Proceeding in this way we get the generalized value of

$$U(m,n) = \begin{cases} 2 & if \ m = 0, n = 1\\ \frac{1}{m!n!}, \ otherwise \end{cases}$$

Substituting all the results we get

$$u(x,t) = e^{x+t} + t \qquad \qquad 3(c)$$

This result coincides with the results getting by various methods.

#### 5. The Non-Linear Goursat Problem

Now we consider the non-linear Goursat problem

$$\frac{\partial^2 u}{\partial x \partial t} = u^n \left( x, t \right) + f \left( x, t \right) \quad (7)$$

$$u(x,0) = g(x), u(0,t) = h(t)$$
  
 $u(0,0) = g(0) = h(0)$ 

Here  $u^n(x,t)$  is a non-linear term.

Example 4: The non-linear Goursat problem is

$$\frac{\partial^2 u}{\partial x \partial t} = (x+t)^3 - u^3$$
$$= x^3 + 3x^2 + 3xt^2 + t^3 - u^3 \qquad 4(a)$$

$$u(x,0) = x, \quad u(0,t) = t, \quad u(0,0) = 0 \quad 4(b)$$

Using the Differential Transform to the equation 4(a) and 4(b) and using the property we get,

$$DT\left(\frac{\partial^2 u}{\partial x \partial t}\right) = -DT\left(u^3\right) + DT\left(x^3 + 3x^2 + 3xt^2 + t^3\right)$$
$$DTu\left(x, 0\right) = DTx, \quad DT u\left(0, t\right)$$
$$= DTt, \quad DTu\left(0, 0\right) = DT0$$

$$(m+1)(n+1)U(m+1,n+1)$$
  
=  $\sum_{r=0}^{m} \sum_{l=0}^{m-r} \sum_{s=0}^{n} \sum_{p=0}^{n-s} U(r,n-s)$   
-  $p)U(l,s)U(m-r-l,p)$   
+  $\delta(m-3,n)$   
+  $3\delta(m-2,n-1)$   
+  $3\delta(m-1,n-2)$   
+  $\delta(m,n-3)$ 

а

$$U(m-0) = \delta(m-1), U(0,n) = \delta(n-1),$$
$$U(0,0) = 0.$$
$$U(m,n) = \begin{cases} 1, & \text{if } m = 1, n = 0, \\ 1, & \text{if } m = 0, n = 1, \\ 0 & \text{otherwise} \end{cases}$$

Substituting all the results we get

$$u(x,t) = x + t \qquad 4(c)$$

This result coincides with the results getting by various methods.

### 6. Conclusion

In this study, we presented an analytical framework to tackle the linear and non-linear Goursat problems and got a unique result which was calculated easily than other traditional numerical methods. This is an attractive, improved and novel way to solve easily mathematical calculations and significant opportunities for the utilization of Two-dimensional Differential Transform method for future research avenues. All the calculations can be done by simple manipulations. Several examples were tested through using the Two-dimensional Differential Transform Method (DTM) and the results showed the simplicity and accuracy of this method. This review is an attempt to application the recent approaches in mathematics and searching how DTM plays an important role in solving various complicated problems. We conclude that this promising DTM method is reliable and accurate than other existing methods.

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