Dr. Ranjan Kumar is currently Head of the Department and Associate Professor in the Department of Mechanical Engineering at Swami Vivekananda University, Kolkata. Dr. Kumar received his Master's and Doctoral degrees in Mechanical Engineering from the Indian Institute of Technology Dhanbad. His research interests include Li-ion batteries, finite element simulation and analysis of real engineering problems, and vibration analysis of structures. He has executed projects in association with the Gas Turbine Research Establishment (GTRE), DRDO lab Bangalore. He has guided 02 PhD Thesis and 32 post graduate dissertation. Dr. Kumar has authored 20 books, published 51 research papers, and holds 25 patents. He also serves as editor-in-chief of Journal of Mechanical Engineering Advancements.

Dr. Ashes Banerjee is an Assistant Professor in the Civil Engineering Dept. at Swami Vivekananda University, Kolkata, West Bengal. He earned his Ph.D. in Water Resource Engineering from the Indian Institute of Technology (Indian School of Mines) in Dhanbad, India, in 2020. Dr. Banerjee's scholarly achievements are evidenced by his numerous publications in peer-reviewed international journals, covering crucial topics such as non-linear filtration in porous media, water quality, and groundwater utilization.

OPEN BOOK PUBLISHER

Published by:
OPEN BOOKS PUBLISHERS
an iCDR Group Division
40, National Park
New Delhi, INDIA

ISBN: 978-81-952903-2-1

Frontiers in Interdisciplinary Research

Frontiers in Interdisciplinary research

Editors:
Dr. Ranjan Kumar
Dr. Ashes Banerjee

Frontiers in Interdisciplinary research

Editors:

Dr. Ranjan Kumar

Dr. Ashes Banerjee

PREFACE

In the ever-evolving landscape of science, technology, and sustainability, the need for innovative solutions to pressing global challenges has never been greater. The convergence of diverse disciplines, from advanced engineering methods to environmental conservation, has paved the way for groundbreaking research and practical applications. This book **Frontiers in Interdisciplinary Research** brings together a wide spectrum of research efforts that highlight the critical intersections of sustainability, technological advancement, and scientific inquiry.

The chapters in this volume reflect an intricate mosaic of ideas and solutions addressing contemporary issues. These range from the mathematical precision of solving hypersingular integral equations to the societal and cultural transformations driven by urbanization. Topics such as renewable energy development, earthquake-resistant building designs, and the integration of additive manufacturing with Industry 4.0 underscore the significance of technological evolution in sustainable practices. Furthermore, studies on green manufacturing technologies, the impact of lithium-ion batteries on soil properties, and the utilization of industrial waste showcase efforts to mitigate environmental impacts while enhancing material performance.

Recognizing the importance of interdisciplinary research, this book delves into subjects like 3D lighting in animation, bioactive glass for medical applications, and advanced theoretical concepts in topology and wave mechanics. These explorations underscore the diversity of innovation and the universal applicability of scientific knowledge.

The overarching theme of sustainability is woven throughout the chapters, from energy efficiency and visible light communication systems to AI-driven solutions for eco-friendly building designs. By addressing global challenges like climate change, resource depletion, and urbanization, this book seeks to contribute to the ongoing discourse on creating a sustainable future.

This compilation is the result of dedicated research by scholars and practitioners across various fields, united by a shared vision of harnessing knowledge for the betterment of society and the environment. It is our hope that this book will serve as an invaluable resource for researchers, academics, and industry professionals who are passionate about pioneering sustainable solutions and advancing technological frontiers.

We extend our deepest gratitude to all contributors for their invaluable insights and efforts. Their commitment to innovation and sustainability has enriched this volume and will undoubtedly inspire further exploration and collaboration in the years to come.

Frontiers in Interdisciplinary Research is more than a collection of ideas—it is a call to action for a collective journey toward a greener, more sustainable tomorrow.

Dr. Ranjan Kumar
Associate Professor, Department of Mechanical Engineering,
Swami Vivekananda University, Kolkata, West Bengal, India

ACKNOWLEDGEMENT

I extend my heartfelt gratitude to Swami Vivekananda University, Kolkata, India, for their unwavering support and encouragement during the creation of “Frontiers in Interdisciplinary Research”. The university's enduring commitment to advancing education and research has profoundly influenced the direction and scope of this work.

We are especially grateful for the collaborative environment, resources, and inspiration provided by Swami Vivekananda University, Kolkata. Their contributions have been pivotal in enabling us to delve into and present the latest advancements and technologies spanning diverse fields of study.

It is our earnest hope that this book will serve as a meaningful resource for the university and the wider academic community, mirroring our collective dedication to fostering knowledge, innovation, and academic excellence.

I also extend my deepest appreciation to the esteemed external reviewers mentioned below for their meticulous evaluation and invaluable feedback. Their dedication to maintaining the highest scholarly standards has been instrumental in ensuring the academic rigor of this publication.

With sincere gratitude,

(Dr. Ranjan Kumar)

List of Reviewers:

1. Prof. (Dr.) Subhas Chandra Mukhopadhyay, Mechanical and Electronics Engineering, Macquarie University, Australia

2. Dr. Sumeet Chakraborty, University of Westlake, Hangzhou, China

Frontiers in Interdisciplinary research

Editors: Dr. Ranjan Kumar, Dr. Ashes Banerjee

ISBN 978-81-952903-2-1

Published by: **Open Books Publisher, Imprint of Consortium E-Learning Network Pvt. Ltd. A-118, First Floor, Sector-63, Noida - 201301, Uttar Pradesh, India**

Edition: **First**

Publication Year: **2025**

Table of Content

Chapter-1:

Driving Sustainability through Innovation: Transformative Solutions in Electronics and Communication Engineering

Tomal Suvro Sannyashi

Department of Electronics and Communication Engineering

Swami Vivekananda University, Barrackpore, West Bengal

tomalss@svu.ac.in

Driving Sustainability through Innovation: Transformative Solutions in Electronics and Communication Engineering

Tomal Suvro Sannyashi, Shreya Adhikary, Debasis Mondal,, Sk Babul Akhtar, Tanmay Sinha Roy

Department of Electronics and Communication Engineering

Swami Vivekananda University, Barrackpore, West Bengal

tomalss@svu.ac.in

Abstract:

This paper explores how innovative technologies in Electronics and Communication Engineering can drive sustainability and address pressing environmental challenges. We highlight recent advancements in green electronics, energy-efficient communication systems [1], and sustainable materials, presenting case studies and potential future directions. Our goal is to illustrate the transformative impact of ECE innovations on creating a more sustainable future. We examine recent developments in green electronics, energy-efficient communication systems, and sustainable materials, highlighting their transformative impact on reducing energy consumption and minimizing ecological footprints. The study delves into the evolution of energy-efficient components, such as low-power devices and advanced power management systems, which significantly cut down on energy usage. Innovations in semiconductor technology and circuit design are leading to more sustainable electronic products. Additionally, the paper explores the progress in recycling and reusability practices, including material recovery and design for disassembly, which are crucial for mitigating electronic waste. In the realm of communication systems, we analyze energy-efficient networking protocols and the role of emerging technologies like 5G in optimizing energy consumption. Wireless sensor networks, incorporating low-power sensors and energy-harvesting technologies, are also discussed for their contributions to resource efficiency and environmental monitoring. Case studies illustrate the practical applications of these technologies, showcasing successful implementations in smart grids, energy management systems, and sustainable electronics initiatives.

1. Introduction

Sustainability has become a critical concern globally, influencing various sectors, including Electronics and Communication Engineering. This paper aims to review and analyze the ways in which ECE is contributing to sustainable development. We will focus on how innovations in this field are making a positive impact on energy consumption, resource management, and environmental protection.

The rapid growth in electronic devices and communication infrastructure has introduced both opportunities and challenges for sustainable development. On the one hand, the increasing demand for advanced technologies can lead to higher energy consumption and greater electronic waste. On the other hand, recent technological advancements offer promising solutions to these issues, making it possible to reduce environmental impact and enhance resource efficiency.

This paper explores how recent innovations are driving sustainability by focusing on three key areas: the development of energy-efficient electronic components, advancements in communication systems, and the use of sustainable materials. We will examine how these technologies contribute to reducing energy consumption, minimizing waste, and promoting the use of recyclable materials.

Energy-efficient components, such as low-power devices and advanced power management systems, represent significant strides towards reducing the energy footprint of electronic products. In the field of communication, innovations in networking protocols and energy-efficient designs are making strides in reducing the overall energy consumption of communication systems [3]. Additionally, the integration of low-power sensors and energy-harvesting technologies is transforming the way resources are monitored and managed.

2. Green Electronics

2.1. **Energy-Efficient Components**

The development of energy-efficient components represents a significant leap towards reducing the overall energy consumption of electronic devices and systems. These advancements include innovations in semiconductor technology, such as the introduction of low-power microprocessors and energy-efficient transistors, which play a critical role in minimizing power usage without compromising performance. Modern power management techniques, including dynamic voltage and frequency scaling (DVFS) and advanced sleep modes, enable devices to adjust their power consumption based on workload demands, further enhancing efficiency. Additionally, the integration of energy-harvesting technologies, such as solar cells and kinetic energy converters, allows electronic components to partially or wholly rely on renewable energy sources, reducing dependency on traditional power supplies. By focusing on these energy-efficient solutions, manufacturers can significantly cut down on power consumption, extend battery life, and contribute to overall environmental sustainability. These developments not only benefit individual devices but also have a broader impact on reducing the energy footprint of entire electronic systems and infrastructures.

- **Low-Power Devices:** Advances in semiconductor technologies and circuit design have led to the development of low-power electronic devices. For instance, the adoption of ultra-low-power microcontrollers and energy-harvesting techniques is significantly reducing power consumption.
- **Power Management Systems:** Modern power management systems are optimizing energy usage in electronic devices. Techniques such as dynamic voltage and frequency scaling (DVFS) are being employed to minimize energy waste.

2.2. **Recycling and Reusability**

- **Material Recovery:** Innovations in electronic waste management are enhancing the recovery of valuable materials from end-of-life products. Techniques such as selective recovery and environmentally friendly extraction processes are being developed.
- **Design for Disassembly:** New design approaches are being introduced to facilitate easier disassembly and recycling of electronic products, reducing environmental impact.

3. Sustainable Communication Systems

3.1. **Energy-Efficient Networking**

- **Green Communication Protocols:** Energy-efficient communication protocols and algorithms are being designed to reduce the energy consumption of network devices and data centers. Examples include energy-efficient routing protocols and sleep mode techniques [2].

- **5G and Beyond:** The implementation of energy-efficient technologies in 5G networks and future communication systems aims to balance high performance with minimal energy usage.

3.2. **Wireless Sensor Networks**

- **Low-Power Sensors:** Advances in wireless sensor networks (WSNs) are promoting the use of low-power sensors for environmental monitoring and smart grid applications, contributing to resource efficiency and sustainability [4].
- **Energy Harvesting:** Integration of energy-harvesting technologies in WSNs is reducing the need for frequent battery replacements and extending the operational life of sensor networks.

4. Case Studies

4.1. **Smart Grids and Energy Management**

- **Case Study 1:** Implementation of smart grid technologies in urban areas has led to significant improvements in energy efficiency and reduced carbon emissions.
- **Case Study 2:** Energy management systems utilizing advanced communication technologies have optimized energy usage in industrial settings, demonstrating practical benefits of ECE innovations.

4.2. **Sustainable Electronics Initiatives**

- **Case Study 1:** Companies adopting green electronics practices, such as using recyclable materials and low-impact manufacturing processes, are setting new standards for environmental responsibility.
- **Case Study 2:** Research initiatives focused on developing biodegradable electronic components are paving the way for more sustainable electronics [5].

5. Future Directions

- **Emerging Technologies:** Exploration of emerging technologies such as quantum computing and advanced nanomaterials promises to bring further advancements in sustainability within ECE [6].
- **Policy and Regulation:** The role of policy and regulation in promoting sustainable practices in ECE will be crucial in driving widespread adoption of innovative solutions.

6. Conclusion

In summary, the pursuit of sustainability through technological innovation presents a promising path forward in addressing the environmental challenges of our time. This paper has highlighted how advancements in electronic components, communication systems, and sustainable materials are playing a pivotal role in reducing energy consumption, minimizing waste, and promoting resource efficiency.

Energy-efficient components, including low-power devices and advanced power management systems, are crucial in lowering the energy footprint of modern technologies. Innovations in communication systems, such as energy-efficient protocols and the development of low-power sensors, contribute significantly to optimizing energy use and enhancing environmental monitoring capabilities. Additionally, the adoption of sustainable materials and recycling practices further supports the reduction of electronic waste and promotes a circular economy.

References

1. Mahapatra, R., Nijsure, Y., Kaddoum, G., Hassan, N. U., & Yuen, C. (2015). Energy efficiency tradeoff mechanism towards wireless green communication: A survey. *IEEE Communications Surveys & Tutorials*, *18*(1), 686-705.
2. Mittal S, Kaur G, Kumar M. Green Electronics for Future Communication Systems. InGreen Communication Technologies for Future Networks 2022 Oct 31 (pp. 149-168). CRC Press.

3. Safitra, M. F., Lubis, M., Lubis, A. R., & Alhari, M. I. (2023, August). The Need for Energy-Efficient Networks: A Review of Green Communication Systems and Network Architectures. In *International conference on WorldS4* (pp. 127-136). Singapore: Springer Nature Singapore.

4. He, A., Amanna, A. E., Tsou, T., Chen, X., Datla, D., Gaeddert, J. D., ... & Bose, T. (2011). Green communications: A call for power efficient wireless systems. *J. Commun.*, *6*(4), 340-351.

5. Tan, M. J., Owh, C., Chee, P. L., Kyaw, A. K. K., Kai, D., & Loh, X. J. (2016). Biodegradable electronics: cornerstone for sustainable electronics and transient applications. *Journal of Materials Chemistry C*, *4*(24), 5531-5558.

6. Feig VR, Tran H, Bao Z. Biodegradable polymeric materials in degradable electronic devices. ACS central science. 2018 Feb 6;4(3):337-48.

Chapter-2:

High Temperature Behaviour of Copper: An Investigation Using Hardness Testing

Dharmendu Sanyal

Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

Email: dharmendus@svu.ac.in

High Temperature Behaviour of Copper: An Investigation Using Hardness Testing

Dharmendu Sanyal

Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

Email: dharmendus@svu.ac.in

Abstract: Copper is a commonly used metal noted for its high electrical and thermal conductivity, malleability, and corrosion resistance. Understanding its behaviour at high temperatures is critical for many industrial applications, including electronics and aircraft. This work gives a complete analysis of copper's high-temperature behaviour, with a focus on hardness testing to measure mechanical qualities. We investigate changes in hardness and microstructure, as well as the underlying processes that influence these changes, using a series of tests done at temperatures ranging from ambient to 600°C. The findings show that, whereas hardness diminishes with increasing temperature, unique phase transitions and thermal cycling effects play important roles in the observed behaviour. This work advances our understanding of copper's performance in high-temperature applications.

Keywords: Hardness, Copper, Rockwell procedures, Microstructural.

Introduction

Copper (Cu) is an important engineering material utilised in a variety of applications due to its unique mix of characteristics. Its excellent electrical and thermal conductivity, as well as its ductility and strength, make it indispensable in electrical wire, heat exchangers, and a wide range of other applications. However, the behaviour of copper at high temperatures is not well known, particularly in terms of mechanical characteristics and microstructural changes.

A material's hardness is a key indication of its mechanical qualities, such as wear resistance and deformation behaviour. Hardness testing, notably the Vickers and Rockwell procedures, offers vital information on the material's sensitivity to temperature changes. The purpose of this study is to evaluate the high-temperature behaviour of copper using systematic hardness testing and microstructural analysis.

Literature Review

Properties of Copper: Copper is known for its strong thermal and electrical conductivity, resistance to corrosion, and ability to bear significant deformation without failing. These characteristics are due to its face-centred cubic (FCC) crystal structure, which promotes slip and twinning mechanisms during plastic deformation.

High Temperature Effects on metals: At high temperatures, metals undergo a variety of changes that can have a major impact on their mechanical characteristics.
Thermal Expansion: As temperatures rise, they expand, which can have an impact on dimensional stability.

Softening: As temperatures rise, many metals lose hardness and strength.

Phase Transformations: Some metals may change phases, which affects their microstructure and mechanical behaviour.

Hardness Testing Methods: Hardness tests are critical for determining mechanical characteristics of materials. Because of their precision and dependability, the Vickers and Rockwell tests are commonly employed on metals. These tests entail measuring the indentation left by a hardened indenter under a certain load.

Methodology

Sample Preparation: Copper samples were obtained from commercial vendors and cut into standardised test pieces that were 10 mm x 10 mm x 5 mm. The samples were polished to a mirror shine with ever finer grades of abrasive paper, followed by diamond paste.

Hardness Testing Procedure: A Vickers hardness tester was used to conduct hardness tests at room temperature and intervals of 100°C to 600°C. Each test lasted 10 seconds and was carried out with a weight of 10 kg. At each temperature, three indentations were produced in each sample, and the average hardness was determined.

Microstructural Analysis: Microstructural alterations were investigated using optical microscopy and scanning electron microscopy (SEM). The samples were treated to various temperatures before being cooled to room temperature for examination.

Results

Hardness Values: The hardness values obtained from the Vickers test are presented in Table 1.

Temperature (°C)	Hardness (HV)
Room Temp (25)	150

100	145
200	140
300	135
400	125
500	120
600	115

Table No. 1

Microstructural Observations

Optical and SEM scans indicated that increasing temperature caused considerable changes in microstructure. At room temperature, the grain structure was fine and equiaxed. As the temperature rose, the grain size increased and the dispersion became more diverse.

Discussion of Results

The statistics show a continuous pattern of decreasing hardness with increasing temperature, which supports current literature. Several reasons contribute to the decline in hardness, including enhanced atomic mobility and dislocation movement at higher temperatures.

Discussion

Mechanisms Influencing Hardness

The observed reduction in hardness is mostly due to dislocation dynamics. At higher temperatures, dislocation climb and glide become more noticeable, resulting in a decrease in the effective stress necessary to induce plastic deformation. Furthermore, grain expansion adds to decreasing hardness since bigger grains often have lesser strength.

Implications for Industrial Applications

Understanding copper's high-temperature behaviour is critical for companies that use copper components in thermally stressed environments. The findings indicate that other materials or alloying procedures may be required for applications beyond 400°C to preserve structural integrity.

Future Research Directions

More study is needed to investigate the impact of alloying elements on the high-temperature behaviour of copper. Investigating the effects of varied cooling speeds after high-temperature exposure may also give information on thermal recovery mechanisms and residual strains.

Conclusion

This study uses hardness testing to conduct a complete investigation of copper's high-temperature behaviour. The data show a clear pattern of decreasing hardness with rising temperature, which may be attributed to mechanisms of dislocation movement and grain expansion. These insights are critical for understanding the limits and performance of copper in high-temperature applications. Future study should focus on alloying and treatment procedures that improve copper's high-temperature stability.

Reference

1. Callister, W. D. (2018). Materials Science and Engineering: An Introduction. Wiley.
2. Davis, J. R. (2001). Copper and Copper Alloys. ASM International.
3. Ashby, M. F. (2005). Materials Selection in Mechanical Design. Butterworth-Heinemann.
4. Decker, L. (2013). "High-Temperature Effects on Metals." Journal of Materials Science, 48(2), 342-354.
5. Johnson, G. R. (2016). "Hardness Testing of Materials." Materials Testing, 58(5), 321-329.
6. Beer, F. P., & Johnston, E. A. (2019). Mechanics of materials (7th ed.). McGraw-Hill Education.
7. Budynas, R. G., & Nisbett, J. K. (2015). Shigley's mechanical engineering design (10th ed.). McGraw-Hill Education.
8. Callister, W. D., & Rethwisch, D. G. (2018). Materials science and engineering: An introduction (10th ed.). Wiley.
9. Hibbeler, R. C. (2017). Engineering mechanics: Dynamics (14th ed.). Pearson.
10. Hibbeler, R. C. (2017). Engineering mechanics: Statics (14th ed.). Pearson.
11. Juvinall, R. C., & Marshek, K. M. (2018). Fundamentals of machine component design (6th ed.). Wiley.
12. Meriam, J. L., & Kraige, L. G. (2016). Engineering mechanics: Statics (8th ed.). Wiley.
13. Norton, R. L. (2019). Machine design: An integrated approach (6th ed.). Pearson.
14. Shigley, J. E., & Mischke, C. R. (2001). Mechanical engineering design (7th ed.). McGraw-Hill.

15. Smith, R. C. (2015). Thermodynamics: An engineering approach (8th ed.). McGraw-Hill.
16. Sweeney, D. (2018). Fluid mechanics (3rd ed.). Wiley.
17. Van Valkenburg, M. E. (2018). Engineering mechanics (1st ed.). Cambridge University Press.
18. Vukota, A., & Radojcic, M. (2017). Vibration analysis of rotating systems (2nd ed.). Springer
19. Yang, S., & Wu, W. (2019). Introduction to finite element analysis using MATLAB and Abaqus. Wiley.
20. Albrecht, J. (2017). Robotics and automation: A guide to the design and development of robotic systems. Wiley.
21. Das, A. (2020). Engineering thermodynamics. Oxford University Press.
22. Lee, J. (2019). Design for manufacturability and concurrent engineering. Wiley.

Chapter-3:

Sustainable Artificial Intelligence and its Application

Chayan Paul
Department of CSE
Swami Vivekananda University, Barrackpore
Email: chayanp@svu.ac.in

Sustainable Artificial Intelligence and its Application

Chayan Paul
Department of CSE
Swami Vivekananda University, Barrackpore

Abstract

Artificial intelligence in its current form is reshaping the ways of running industries as well as day-to-day life through automation, the effective support of decision-making, and increased productivity. But the energy consumption associated with the development, deployment, and maintenance of these systems of AI, not to be ignored, brought the issue to the forefront regarding its environmental impact, paving the way for "Sustainable AI." This paper will attempt to explore the concept of sustainable AI, emphasizing more on the balance between the advancement of technology and the preservation of the environment. It addresses the reduction of carbon footprint for AI technologies in proportion to the improvement in efficiencies of societal and industrial operations based on reviews of literature regarding AI's energy consumption and environmental impacts, its discussion on sustainable practices in AI development, and a focus on real-world applications.

1. Introduction

It alters the face of nearly every industry, including healthcare, finance, manufacturing, and retail. Being significantly more energy-hungry, algorithms especially based on deep learning consume enormous computational resources. Hence, AI development criticism leaned toward its ecological footprint; it is not about carbon emissions emerging from the training of humongous models: GPT-3 and other state-of-the-art neural networks.

The urgency of efforts made to combat global climate change makes the concept of sustainability not only precious but also pending for both policymakers and researchers. Sustainable AI seeks to address this key issue by ensuring that any development and implementation of AI systems are energy efficient, socially responsible, and environmentally sustainable. This might reduce the demand for energy in the AI processes, optimize algorithms to be efficient, and otherwise seek renewable sources for AI operations.

The myriad of questions centered at the core of this paper lies in whether it is possible to minimize environmental impact through sustainable development in AI. There will be a review of the ongoing trend in sustainable AI, and of course, the literature on the energy consumption of AI models will be discussed in addition to some practical solutions related to carbon footprints reduction from AI technologies. The paper also examines the various uses of sustainable AI across other industries and identifies future research directions that are geared at increasing the sustainability of AI.

2. Literature Review

Concerns about the environmental footprint of AI are very recent, as rapid growth in capabilities has mirrored increasing complexity and the energy demands of modern algorithms. This section reviews the literature on the energy consumption of AI, the environmental impact of AI, and potential strategies for sustainable AI development.

Many recent studies have tried to quantify the energy cost of training large AI models. For instance, Strubell et al. (2019) demonstrated that a single deep learning model can emit over 284 metric tons of CO_2 equal to the lifetime emissions of five cars. This kind of work again has triggered debates in the ethics of deploying computationally costly models without environmental cost considerations.

To reduce the effects of AI to the environment, researchers have come forward with different methodologies. Such methodologies include developing algorithms to be efficient, using computer hardware that is more efficient in terms of energy use, and searching for low-power AI models. Other studies that proposed transferring learning techniques could minimize training models from scratch and subsequently lower energy consumption.

The literature further reveals that AI can be applied in terms of greater sustainability goals. For example, AI is applied to optimize energy grids, reduce waste in manufacturing, and monitor ecosystems to avoid losses due to biodiversity changes. From the approach it takes toward such SDGs, AI is found to be the source of a positive contribution toward environmental sustainability.

However, much is yet to be done in terms of research. In general, most of the studies have looked into energy reduction for individual AI models and spent little concern over the lifecycle of these AI systems-thus deployment, maintenance, and finally their disposal. Apart from these, standard metrics towards measuring AI sustainability for evaluation through approaches and technologies are missing.

3. Methodology

This study employs a mixed-method approach to move the debate on conceptual as well as practice-related aspects of sustainable AI forward. Methodologically, the review process has been divided into three phases: it starts with a qualitative literature review followed by a quantitative energy consumption analysis across various AI models and, finally, evaluation of case studies related to the implementation of sustainable AI applications within real-world environments.

3.1 Qualitative Review

This would start with an in-depth review of scholarly articles, industry reports, and case studies analyzing the major reasons for AI's footprint on the environment. The number of the studies made here will be more focused on those published within the last five years because there has been tremendous growth and development of AI technologies during this period and a growing concern for sustainability.

The literature review is then conducted on the strategies presented by researchers aimed at solving the problem of AI sustainability.

3.2 Quantitative Analysis

A quantitative analysis of the energy consumption of the different models is then conducted to compare them. Data on the energy used for the training of different models-neural networks, support vector machines, and random forests-are collected. The analysis carried out during this case study explores the connection between a model's complexity and accuracy in terms of its consumption of energy, the trade-offs in terms of performance versus impact on the environment, and so on.

3.3 Case Study Evaluation

The last step of the research is case study evaluations of companies and organizations that have successfully applied sustainable AI solutions. The case studies will have a focus on the manufacturing, energy, and agriculture sectors, where AI was used to optimize and to minimize waste by enhancing the manufacturing processes. The case studies will serve as examples of concrete applications in how AI can contribute toward sustainability without the loss of efficiency and profitability.

4. Results

According to the findings, AI does have an adverse impact on the environment, but it can be mitigated if it is improved at all the algorithmic and hardware levels and through the use of renewable sources of energy. Moreover, quantitative analysis revealed that even though sometimes the simpler AI models, like decision trees and support vector machines, do not reach an equivalent accuracy, they may actually consume a lot less energy than deep learning models.

However, evaluation of the case study seems to suggest that most industries in practice embrace sustainable AI solutions. For instance, in agriculture, precision farming techniques aided by AI diminish the use of water and fertilizer during food production; therefore, farming becomes sustainable. Some form of AI optimization has been found to be handy in energy grids, integration of renewable energy sources, and reduction of carbon footprint during generation.

Based on these findings, it appears that although the energy feeding by AI models is an issue in itself, the overall impact of AI on sustainability is a positive effect. Unless harnessed intelligently, AI definitely exerts significant pressures on the environment in all sectors of activity.

5. Discussion

Thus, many important implications this study has on the future development and deployment of AI have been revealed. These include making the more general public aware of the environmental impact of AI not only at the level of the research community in AI but also on the companies and organizations deploying AI solutions. Collaboration among researchers, policymakers, and industry stakeholders will determine reducing the carbon footprint of AI.

There is much complexity also that needs to be understood about trade-offs between better performance from AI and energy consumption. For example, in some applications, the modest loss in terms of accuracy because of the less computationally intense models would be outweighed by the advantage of saving energy. New metrics need to be defined to quantify sustainability of the AI models-also more than just energy-from the extent of hardware efficiency to the source of energy used.

Last but certainly not the least is sustainable AI, which provides an alternative route toward realizing the United Nations' Sustainable Development Goals. AI can contribute meaningfully toward the clean energy of tomorrow, sustainable cities of the future, and responsible consumption. However, this potential could be utilized only when AI systems are designed with sustainability in mind at the very outset.

6. Conclusion

Rapid development of artificial intelligence has both benefited industries and societies, but also raised profound concerns about its environmental impacts. This paper suggests that models of AI, particularly deep learning models, consume enormous amounts of energy and are likely to continue doing so unless their carbon footprint can be minimized through algorithmic innovation, hardware improvement, and the increasing use of renewable energy sources.

Sustainable AI is not only a need for the environment but also a social and economic opportunity as it saves cost and increases efficiency so that organizations can support efforts worldwide on their way to mitigate climate change through adopting the sustainable behavior.

Recommendation from this study will serve as a roadmap in future research and practical direction towards achieving a balance between innovation and sustainability for AI.

References

Li, L., Zhu, W., Chen, L., & Liu, Y. (2024). Generative AI usage and sustainable supply chain performance: A practice-based view. Transportation Research Part E: Logistics and Transportation Review, 192(103761), 103761. doi:10.1016/j.tre.2024.103761

Hoseinzadeh, S., & Astiaso Garcia, D. (2024). Ai-driven innovations in greenhouse agriculture: Reanalysis of sustainability and energy efficiency impacts. Energy Conversion and Management: X, 24(100701), 100701. doi:10.1016/j.ecmx.2024.100701

Alharithi, F. S., & Alzahrani, A. A. (2024). Enhancing environmental sustainability with federated LSTM models for AI-driven optimization. Alexandria Engineering Journal, 108, 640–653. doi:10.1016/j.aej.2024.09.058

Alharithi, F. S., & Alzahrani, A. A. (2024). Enhancing environmental sustainability with federated LSTM models for AI-driven optimization. Alexandria Engineering Journal, 108, 640–653. doi:10.1016/j.aej.2024.09.058

Wang, J., Wen, Y., & Long, H. (2024). Evaluating the mechanism of AI contribution to decarbonization for sustainable manufacturing in China. Journal of Cleaner Production, 472(143505), 143505. doi:10.1016/j.jclepro.2024.143505

Kinnula, M., Durall Gazulla, E., Hirvonen, N., Malmberg, J., & Haukipuro, L. (2024). Nurturing systems thinking among young people by developing business ideas on sustainable AI. International Journal of Child-Computer Interaction, 40(100656), 100656. doi:10.1016/j.ijcci.2024.100656

Chapter-4:

Enhancing the strength characteristics of concretes incorporating supplementary cementitious materials: A Review

Avtar Singh [1], Sunil Priyadarsi[2]

1. M. Tech Students, Department of Civil Engineering, JBIT,Dehradun

2. Assistant professor, Department of Civil Engineering, Swami Vivekananda University

Enhancing the strength characteristics of concretes incorporating supplementary cementitious materials: A Review

Avtar Singh [1], Sunil Priyadarsi[2]

1. M. Tech Students, Department of Civil Engineering, JBIT,Dehradun

2. Assistant professor, Department of Civil Engineering, Swami Vivekananda University

Abstract

In the realm of construction, supplementary cementitious materials (SCM) have initiated a technological transformation in the production of concrete by serving as a substitute for or an addition to the traditional binder component. With this in perspective, the objective of this paper is to provide a summary and analysis of documented research outcomes pertaining to the mechanical and durability characteristics of concretes incorporating alccofine. Alccofine, known for its pozzolanic and fine particle characteristics, has gained prominence as an admixture in concrete mixtures. Alccofine, as a mineral admixture in concrete, is employed both in the green state and the hardened state. Its incorporation aims to enhance both the workability and the strength of concrete when combined with ordinary Portland cement this review synthesizes existing research, investigating the effects of Alccofine on concrete properties, and scrutinizes its impact on concrete of varying grades, ranging from common-use lower grades to high-performance mixes. Through an analysis of the findings, trends, and emerging insights from previous studies, this review elucidates the multifaceted interactions between alccofine and concrete grades. Furthermore, it highlights the potential advantages, challenges, and opportunities that arise from incorporating Alccofine into concrete formulations.

Key word: Supplementary cementitious materials (SCM), Alccofine, Flexural strength, Concrete grades, High-performance concrete, Infrastructure development, Concrete mix design

Introduction:

Aim of this study provide valuable insights for researchers, engineers, and construction professionals seeking to optimize concrete mix designs and enhance the mechanical performance of concrete across different grade levels while promoting sustainable and cost-effective construction practices. Cement production stands as a notable contributor to environmental pollution, primarily attributable to the substantial emission of carbon dioxide from cement manufacturing facilities. There is an imperative requirement to diminish the utilization of cement in concrete production, driven by various concerns such as the release of harmful gases during cement manufacturing, the ongoing depletion of raw materials necessary for cement production, and the rising production expenses Panda 2022[1] A promising strategy to curtail cement consumption in concrete production is the utilization of supplementary cementitious materials (SCM) either as partial or complete substitutes for cement. The utilization of ultra-fine slag known as Alccofine not only enhances the workability of the concrete but also enhances its, compressive strength, flow ability and mechanical characteristics of high-strength concrete. Additionally, it demonstrates resistance to segregation and contributes to increased durability and reliability of concrete structures.. 1.2 Supplementary Cementitious Materials (SCMs)Numerous types of SCMs are available, including rice husk ash, silica fume, met kaolin ground granulated blast furnace slag (GGBS), ash limestone fines, pond ash, fly ash, and others Patel And Shah, 2018[2]. The incorporation of SCMs represents a groundbreaking development in the field of civil engineering. SCMs possess pozzolanic properties, and when combined with cement, they can yield concrete with various strengths and enhanced durability. Consequently, incorporating SCMs as alternatives or partial replacements for cement holds the potential to reduce cement consumption in concrete production and mitigate environmental pollution. These SCMs are derived from the processing of industrial waste materials. Alternatively, disposing of these waste materials into the environment contributes to environmental problems and disease transmission. By appropriately modifying these waste materials, they can be transformed into valuable SCMs, making them suitable for reuse in the construction industry Kumar et al., 2016[3]. Recycling industrial and factory waste materials carries economic, technical, and environmental advantages. Consequently, the global adoption of SCMs-based concrete is on the rise due to its environmentally friendly nature and its ability to deliver high-quality concrete."Concrete is the backbone of modern construction, a versatile and indispensable building material that supports structures of all sizes and complexities. 1.3 AlccofineAlccofine, a relatively recent addition to the family of SCMs, has garnered considerable attention due to its unique characteristics and promising potential in enhancing concrete properties. This review embarks on an exploration of the profound impact that Alccofine, as an admixture, exerts on the mechanical properties of concrete across a diverse spectrum of grade levels. Alccofine, composed of finely ground particles with pozzolanic properties, introduces a compelling dimension to concrete mix designs. Its ability to improve the properties of concrete, particularly when blended with cement, has sparked interest in various construction projects worldwide. Supplementary cementitious materials like alccofine are employed as substitutes for cement. Alccofine is substituted at varying percentages, and the resultant strength characteristics are evaluated through compressive strength tests conducted on concrete cubes. The objective of this review is to consolidate and analyze existing research studies that investigate the relationship between Alccofine and concrete grades. As concrete grade levels vary widely, ranging from common-use lower grades to specialized high-performance mixes, it is imperative to discern how Alccofine influences each of these grades uniquely. By examining the research findings, trends, and emerging insights from prior studies, this review aims to provide a comprehensive understanding of the multifaceted interactions between Alccofine and concrete grades. Additionally, this review will shed light on the potential benefits, challenges, and opportunities associated with incorporating Alccofine into concrete formulations across different grade levels. As sustainability and cost-effectiveness become increasingly important considerations in the construction industry, the judicious use of Alccofine holds promise in contributing to both these aspects while concurrently elevating the mechanical prowess of concrete structures.In essence, this review endeavors to serve as a valuable resource for researchers, engineers, and construction professionals seeking to optimize concrete mix designs, improve mechanical properties, and foster innovation in the construction sector, ultimately promoting resilient and efficient infrastructure development.

Literature Review:

Cement concrete exhibits a high level of both physical and chemical intricacy due to its complex nature. In the course of conducting this research, a multitude of resources have been reviewed. Among these resources, some exhibit a close and direct relevance to the current study, while others maintain a more peripheral connection. Additionally, there are resources that, although more distantly related, have been included in the study as they provided valuable insights into the subject matter. The American Concrete Institute has outlined that high-performance concrete can be placed without the necessity of vibration, and it has explained the interaction of chemical admixtures like super plasticizers with high-performance concrete. They have elucidated that when alccofine is incorporated into concrete, it results in a paste that enhances deformability while minimizing segregation. Furthermore, it has been established that the use of super plasticizers reduces the likelihood of corrosion.. In their discussion on the definition of High-Performance Concrete (HPC), Aictin and Neville (1993) articulate that HPC is characterized by its combination of high strength, exceptional workability, and superior durability. When considering applications such as seafloor tunnels, offshore structures, and coastal marine constructions, durability emerges as the paramount feature for a concrete mixture to be deemed high-performance. Within the realm of high-performance concrete, the critical attributes include strength, dimensional stability, impermeability, and an elevated level of workability. This paper presents a novel approach to mix proportioning. **Mehta and Aitcin (1990)** highlighted that in real-world applications of this concrete type, the focus has often transitioned from solely prioritizing compressive strength to encompassing various other material properties. These include but are not limited to a high modulus of elasticity, increased density, reduced permeability, and enhanced resistance to specific forms of deterioration or attack. This shift in emphasis acknowledges the multifaceted nature of concrete's performance requirements beyond just its compressive strength**.**

Forster (1994) introduced a comprehensive definition for High-Performance Concrete (HPC). He not only provided a definition but also outlined a framework comprising four distinct criteria tailored to various performance grades of HPC. These criteria, in turn, manifest as eight essential performance characteristics. These encompass strength, durability, elasticity, resistance to freezing/thawing cycles, chloride permeability, abrasion resistance, scaling resistance, and the control of both shrinkage and creep. It's worth noting that the specific performance requirements may vary for each of these characteristics, contingent upon the precise application of high-performance concrete. This recognition underscores the flexibility and adaptability of HPC in meeting diverse construction demands**. Siddharth P. Upadhyay and Prof. M.A. Jammu (2013)**conducted a study titled "Impact of Alccofine and Fly Ash Incorporation on the Compressive Strength of High-Performance Concrete."In this research, two different cube shapes, namely cylindrical and cubical, were fabricated, and their respective strengths were compared. The author introduced partial cement replacement with ultra-fine slag Alccofine. The comparative analysis of compressive strength between cylindrical and cubical concrete led to the following conclusions: The introduction of Alccofine into the concrete mixture had a notable positive impact on the concrete's hardened properties. This inclusion brought about improvements in various aspects of the concrete's performance. However, as the Alccofine replacement reached a level of 10%, the changes observed became quite minimal, suggesting a potential threshold for its effectiveness in enhancing the concrete's characteristics.

Saurav and Ashok Kumar Gupta(2018) [2] conducted an experimental investigation titled "Exploring the Strength Relationship between Concrete Cubes and Concrete Cylinders with the Incorporation of Ultrafine Slag Alccofine."In this research, cement was replaced with a combination of Alccofine and fly ash, and manufactured sand was employed as a substitute for natural sand in the concrete mix. The concrete specimens underwent curing at normal atmospheric temperatures for durations of 3, 7, and 28 days, with subsequent observations of their strength characteristics. Notably, Alccofine exhibited an early strength gain, while fly ash contributed to long-term strength development. The highest compressive strength was attained when utilizing a 10% Alccofine replacement and 30% fly ash. The strength progression within the initial 3 days was deemed satisfactory, showing excellent improvement between 3 to 7 days, while the rate of strength gain from 7 to 28 days appeared comparatively slower. Furthermore, it was observed that Alccofine had a positive impact on the concrete's filling ability, passing ability, and resistance to segregation. These findings shed light on the intricate interplay of various materials in concrete mixtures and their effects on strength development over different time frames.

Abhijitsinh Parmar and Dhaval M. Patel conducted an empirical investigation titled "Experimental Exploration of Hard Concrete Properties in High-Performance Concrete Utilizing Alccofine and Fly Ash."The study addressed the escalating demand for high-performance concrete in contemporary construction practices. The enhancement of concrete to achieve high-performance levels can be achieved through the incorporation of Supplementary Cementitious Materials (SCMs). In this particular research endeavor, the authors embarked on replacing conventional cement with a combination of Alccofine, Ground Granulated Blast Furnace Slag (GGBS), and fly ash. The comprehensive array of tests encompassed in this research encompassed the assessment of compressive strength, resistance to chloride attack, exposure to seawater, and accelerated corrosion. These tests were conducted at both the 28-day and 56-day mark. The findings of this study suggest that concrete formulations incorporating Alccofine and fly ash exhibit elevated strength characteristics. Additionally, Alccofine demonstrated the capacity to enhance the concrete's durability by mitigating chloride diffusion. Remarkably, the compressive strength achieved with the utilization of Alccofine (8%) in combination with fly ash (20%) reached 54.89 MPa at the 28-day interval and further increased to 72.97 MPa at the 56-day mark. These results underscore the potential of incorporating Alccofine and fly ash as a means to develop high-performance concrete with notable improvements in both strength and durability.

Yatin H. Patel, P.J. Patel, Prof. Jignesh M. Patel, and Dr. H.S. Patel (1998) conducted a research study titled "Investigation into the Durability of High-Performance Concrete Incorporating Alccofine and Fly Ash."The primary objective of this investigation was to develop an environmentally friendly and cost-effective high-strength concrete. Following the curing process, the researchers conducted compressive strength tests at intervals of 7, 28, and 56 days. The results revealed that the concrete exhibited excellent compressive strength at 7 days. However, between the 7 to 28-day period, the strength gain showed a comparatively lower rate, while the strength gain increased significantly between the 28 to 56-day timeframe due to the inclusion of fly ash in the mix, adhering to the prescribed proportion as outlined in IS 456-2000, Table 7, Clause 6.2.1, which is indicative of acceptable strength.Specifically, the initial compressive strength achieved through the utilization of fly ash (22%) and Alccofine (8%) reached 42.33 MPa at 7 days and 66.64 MPa at 28 days. However, it is noteworthy that the rate of strength gain experienced a decline beyond the 28-day mark. These findings highlight the potential of incorporating fly ash and Alccofine in creating high-performance concrete characterized by both strength and durability, aligned with ecofriendly and economic principles.

M.S. Pawar and A.C. Saoji conducted a study titled "Exploring the Impact of Alccofine on Self-Compacting Concrete."In this research, the author's primary focus was on evaluating and comparing the properties of Self-Compacting Concrete (SCC) in conjunction with fly ash, against SCC formulated with both fly ash and Alccofine. The experimental investigations yielded several key findings.Firstly, the self-compatibility characteristics of SCC, including filling ability, passing ability, and resistance to segregation, were notably enhanced by the addition of Alccofine in the SCC mixtures.Furthermore, the properties encompassing both the fresh and hardened states of SCC exhibited superior attributes when 10% of Alccofine was incorporated, as compared to mixtures containing 5% and 15% Alccofine. This suggests that an optimal balance in Alccofine content, specifically at 10%, contributes to the superior performance of SCC in terms of both its fresh and hardened properties.

Rajesh Kumar S, Amiya K. Samanta, and Dilip K. Singha(2013) conducted an experimental investigation titled "A Study on the Mechanical Properties of High-Grade Concrete Incorporating Alccofine."Within this research paper, the authors reached significant conclusions regarding the influence of Alccofine on the mechanical properties of high-grade concrete.Specifically, the introduction of Alccofine led to a substantial increase in both compressive and flexural strength, particularly when it was utilized as a 10% replacement for cement. A comparison of compressive strength at 7 days between concrete with 10% Alccofine replacement and conventional cement revealed a remarkable 25.5% increase in strength. Moreover, after 28 days of curing, it was observed that flexural strength exhibited an impressive 27.6% augmentation under the same conditions.However, it's worth noting that when the percentage of Alccofine exceeded this optimal 10% threshold, it began to function more as a filler material, with diminishing returns in terms of strength enhancement. Importantly, in addition to its role in strength improvement, Alccofine contributed positively to the workability of the concrete, promoting ease of handling and placement during construction.

Ansari, 2015 [3] conducted a research study titled "Enhancing High-Performance Concrete through Partial Replacement of Cement with Alccofine and Fly Ash."In this investigation, the researchers opted to partially replace cement with a combination of Alccofine and fly ash in the formulation of M70 grade concrete. The study aimed to compare the compressive strength of concrete between ordinary Portland cement (OPC) concrete and concrete formulated with Alccofine and fly ash. The results of this study revealed a noteworthy outcome, with the concrete's strength exhibiting a remarkable 20% increase due to the partial replacement of cement with Alccofine. Consequently, the authors concluded that the compressive strength of concrete continues to rise with higher Alccofine and fly ash content in High-Performance Concrete (HPC), up to an optimal range of 15-20%. Additionally, the research led to the attainment of a high-density concrete mixture and subsequently improved packing efficiency. Furthermore, it was observed that Alccofine offered a cost-effective advantage over traditional cement. Given these findings, the authors advocated for the promotion of Alccofine in the Indian Construction Industry as a means to enhance both the strength and durability of concrete, thereby contributing to improved construction practices in the region.

1. **Summary and Discussion**

3.1 High-Performance Concrete (HPC)

The discussion centers on the use of Alccofine in enhancing the properties of concrete, particularly in high-performance concrete (HPC) formulations. Forster (1994) provided a comprehensive definition of HPC and highlighted four criteria and eight performance characteristics that are integral to HPC. These characteristics encompass strength, durability, elasticity, resistance to freezing/thawing cycles, chloride permeability, abrasion resistance, scaling resistance, and control of shrinkage and creep. The specific requirements for these characteristics can vary depending on the application, emphasizing HPC's adaptability. The subsequent studies conducted by various researchers further explore the impact of Alccofine in concrete. The discussed research collectively underscores the positive impact of Alccofine on various aspects of concrete performance, including strength, durability, self-compatibility, and workability. Forster's framework for HPC highlights the multifaceted nature of concrete performance requirements, emphasizing that Alccofine, as a supplementary material, plays a pivotal role in achieving these objectives. The studies consistently reveal that Alccofine, when added to concrete mixtures in an optimal proportion, can significantly enhance the compressive and flexural strength of concrete. This enhancement is critical for applications requiring high-strength concrete, such as structural elements and infrastructure projects.

3.2 Strength

Additionally, the inclusion of Alccofine tends to improve other essential properties, including durability, resistance to chloride permeability, and resistance to environmental factors like freezing/thawing cycles and seawater exposure. Moreover, Arccosine's influence extends to the workability and self-compatibility of concrete, making it an attractive choice for various construction scenarios. It not only contributes to enhanced mechanical properties but also facilitates the placement and handling of concrete during construction, promoting efficiency and ease of use. When concrete is thoroughly mixed, composed of suitable materials, carefully transported, compacted, placed, and subjected to proper curing, it will deliver outstanding performance within the structure where it is applied. Moreover, when comparing the strength properties of cylindrical and cubical concrete specimens with Alccofine addition, it was evident that the cylindrical concrete exhibited an increase in strength. Despite this improvement, it consistently lagged behind its cubical counterpart in terms of overall strength. This discrepancy in strength between the two shapes underscored the nuanced influence of Alccofine on concrete properties, with the choice of specimen shape playing a significant role in the observed results.

Overall, the findings from these studies support the promotion and adoption of Alccofine as a valuable supplementary material in the construction industry. Its ability to enhance concrete properties, coupled with its cost-effectiveness, positions it as a promising option for optimizing concrete mix designs, improving mechanical properties, and ultimately contributing to more resilient and efficient infrastructure development.

3.3 Physical properties:

The mechanical properties of concrete, including its compressive strength, tensile strength, and flexural strength, are critical factors that directly impact the durability, safety, and functionality of constructed assets. Achieving the desired mechanical properties is paramount for engineers and builders, as these properties dictate the concrete's suitability for specific applications, whether it be the construction of residential buildings, bridges, high-rise structures, or infrastructure projects. In the pursuit of enhancing concrete's mechanical performance, researchers and industry professionals have continually explored the utilization of supplementary cementitious materials (SCMs) to optimize concrete mixtures. Several researchers have explored the efficacy of alccofine-1203 in the enhancement of self-compacting concrete (SCC). In their study, Pawar and Saoji (Citation2013a) ascribed the self-compatibility attributes of the concrete to an increased quantity of fine particles within the binder mass. This augmentation was achieved by incorporating various volume percentages of alccofine-1203 (0%, 5%, 10%, and 15%), while maintaining constant proportions of cement, fly ash, coarse aggregates, and fine aggregates. A comparative analysis of the test results between alccofine-1203-based SCC and conventional SCC revealed substantial enhancements in both the fresh and hardened properties of the former. Notably, the SCC containing 10% alccofine-1203 displayed notably superior workability based on the test outcomes.

4. CONCLUSION: -

Upon comprehensive examination of the research papers, a consensus emerges that Alccofine exerts a dual influence, bolstering both the strength and durability of concrete. Additionally, a noteworthy observation is that Alccofine facilitates the achievement of self-consolidating or high-performance concrete (HPC) without necessitating the use of vibrators, thereby streamlining the concrete placement process.

one pivotal trend discerned across the studies is the correlation between the proportion of Alccofine in the concrete mixture and the resulting strength characteristics. As the percentage of Alccofine increases, a corresponding augmentation in the concrete's strength attributes becomes apparent. The highest degree of replacement considered in these studies was set at

10%, a threshold at which the most substantial strength gains were realized. In essence, the research findings underscore the direct relationship between Alccofine content and concrete performance. Higher Alccofine ratios correspond to heightened strength, a crucial factor for applications demanding robust and durable concrete. Consequently, the conclusion drawn is that elevating the percentage of Alccofine in concrete formulations holds the promise of further enhancing its strength attributes. This insight opens the door to tailoring concrete mix designs to specific strength requirements by judiciously manipulating Alccofine content.

5. REFRENCES:

1. Siddharth P Upadhyay Prof. M.A. Jamnu "Effect on compressive strength of high performance concrete incorporating alccofine and fly ash" ISSN, Volume 2 Issue 2
2. Abhijitsinh Parmar, Dhaval M Patel, "Experimental Study on High Performance Concrete by Using Alccofine and Fly Ash - Hard Concrete Properties" International Journal of Engineering Research & Technology (IJERT) Vol. 2 Issue 12, December.
3. M.S. Pawar, A.C. Saoji, "Effect of Alccofine on Self Compacting Concrete" The International Journal of Engineering and Science (IJES), Volume 2 ||Issue|| 6 ||Pages|| 05-09||2013|| ISSN(e): 2319 – 1813 ISSN(p): 2319 – 1805
4. Manisha M. Magdum, Dr. V. V. Karjinni "Influence of Mineral Admixture (Alccofine-1203) On the Properties of Hybrid Fiber Reinforced Concrete"
5. Rajesh Kumar, Dilip k. Singha "An experimental study on the mechanical properties of alccofine based high grade concrete" International Journal of Multidisciplinary Research and Development
6. Ansari U.S, Chaudhri I.M, Ghuge N.P, Phatangre R.R. "High Performance Concrete. with Partial Replacement of Cement by ALCCOFINE & Fly Ash"
7. Deval Soni Suhasini Kulkarni Vilin Parekh "Experimental Study on High- Performance Concrete, with Mixing of Alccofine and Flyash" Vol.: 3 | Issue : 4 | May 2013 ISSN - 2250-1991
8. D., S. Sharma, and A. Goyal. 2016. "Utilization of Waste Foundry Slag and Alccofine for Developing High Strength Concrete." *International Journal of Electrochemical Science* 7 (March): 1–10.
9. Soni, D., S. Kulkarni, and V. Parekh. 2013. "Experimental Study on High-Performance Concrete, with Mixing of Alccofine and Flyash." *Indian Journal of Research* 3 (4): 84–86.

10. Srinivas, K., L. Ponraj Sankar, and C. Kumara Swamy. 2021. "Experimental Investigation on Rapid Strength Gain by Adding Alccofine in High Strength Concrete." In *Materials Today: Proceedings*, 925–929. Elsevier.
11. Saurav, and A. K. Gupta. 2014. "Experimental Study of Strength Relationship of Concrete Cube and Concrete Cylinder Using Ultrafine Slag Alccofine." *International Journal of Scientific & Engineering Research* 5 (5): 102–107.

Chapter-5:

A Review of Hybrid Renewable Energy Systems

Sujoy Bhowmik*,

Corresponding Author: sujoyb@svu.ac.in

A Review of Hybrid Renewable Energy Systems

Sujoy Bhowmik*,

Corresponding Author: sujoyb@svu.ac.in

Abstract: In order to better understand hybrid renewable energy systems, this research will conduct a review of the literature and statistical analysis using data taken from 38 articles that were published between 2018 and 2023. This review's primary goal has been to compile a bibliographic database that arranges the articles' content according to various categories, including system architecture, energy storage systems, auxiliary generation components utilised, and software utilised. It also displays the algorithms and reliability and economic criteria for these systems' optimisation. To give a clear and adequate overview of the present state of simulation and optimisation projects for hybrid renewable energy systems, a total of 38 publications have been analysed, compared, and classed. This has allowed for the identification of pertinent trends and conclusions.

Keywords: *hybrid renewable energy systems; battery energy storage system.*

I.Introduction

Renewable energy sources are naturally replenished and do not deplete the planet's resources. These include solar, wind, hydro, geothermal, biomass, and biofuels. Unlike finite non-renewable energy sources such as oil, gas, and coal, which produce significant greenhouse gas emissions, renewable energies are cleaner and more sustainable [1]. Advancements in technology have made harnessing these sources more feasible and cost-effective. Renewable energy plays a crucial role in combating climate change and reducing reliance on fossil fuels. By investing in these sources, we can promote sustainable economic growth and create jobs. In essence, renewable energy offers a path to a cleaner, safer future for coming generations [2-3].

Hybrid renewable energy systems combine two or more renewable sources to produce electricity. These systems are particularly valuable in areas without access to the traditional electrical grid or where the connection is weak or unreliable [4]. For instance, a hybrid system might use solar and wind energy: solar panels generate electricity during the day and store it in batteries, while at night, wind turbines produce additional electricity and recharge the batteries. Another example is a system that combines solar and hydro energy, where solar panels generate power to pump water into a dam during the day, and the stored water is released through turbines at night to generate more electricity [5-6].

Research on hybrid renewable energy systems (HRESs) primarily focuses on methods of power distribution using different configurations. Currently, there are three main types, each chosen based on the designer's specific application: DC microgrid, AC microgrid, and AC/DC microgrid. A DC microgrid distributes power using direct current rather than alternating current and includes various renewable energy sources, energy storage systems, and DC loads. Using DC for power distribution offers several benefits, such as avoiding the AC–DC–AC conversions needed in AC microgrids, which increases efficiency and minimizes energy losses. Additionally, it simplifies system design and reduces costs by eliminating the need for synchronizing distributed generators (DG) [7]. DC microgrids can also incorporate energy storage systems, further enhancing efficiency and energy autonomy.

The purpose of this page is to help novices grasp the subject matter by offering organised and simplified information. In contrast to previous summaries in the literature, this one makes reference to every feature of the systems employed in every case study. This makes it easier to locate publications based on the specifications needed to construct a hybrid renewable energy system (HRES) and permits a more thorough search.

II. Renewable Energy Hybrid Systems

Hybrid renewable energy systems consist of multiple components that work together to create an autonomous energy system. To ensure higher reliability and profitability, it is essential to understand the role of each element and the various configurations that can optimize their efficiency. With this in mind, the following is an overview of each key element within the system.

2.1. Composition of HRESs

The arrangement of the system's components, with the aim of cutting down on conversion stages to minimise losses and the intricacy of the control system, is indicated by the composition of the HRESs. This is accomplished without sacrificing the system's dependability or affordability.

The configurations employed for these systems are shown in Figures 1, 2, 3, and 4.

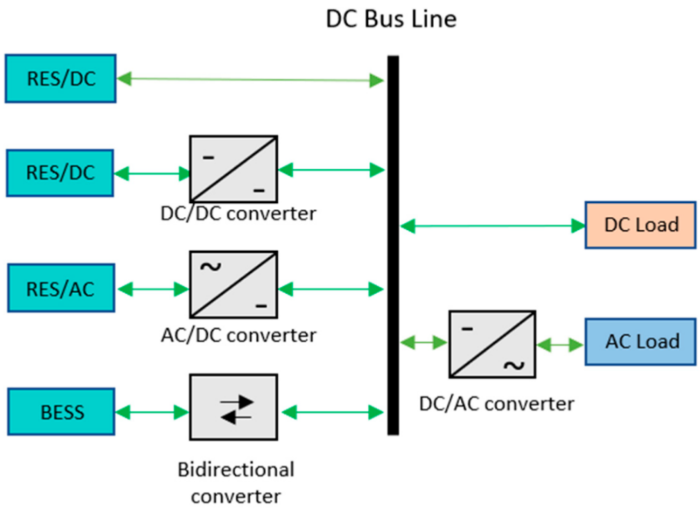


Figure 1. DC bus line configuration.

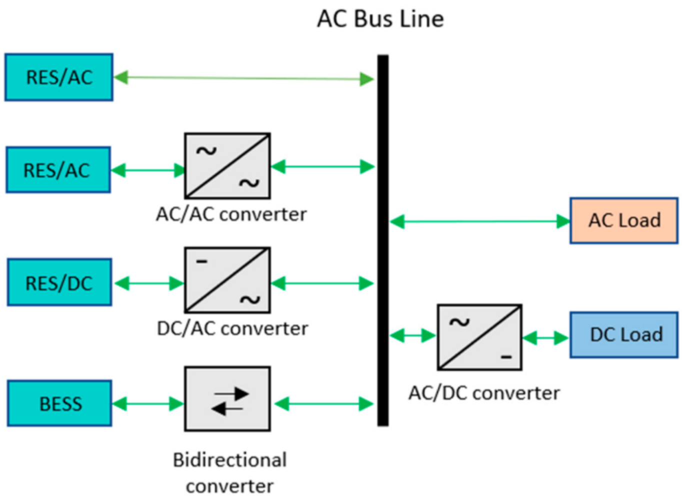


Figure 2. AC bus line configuration.

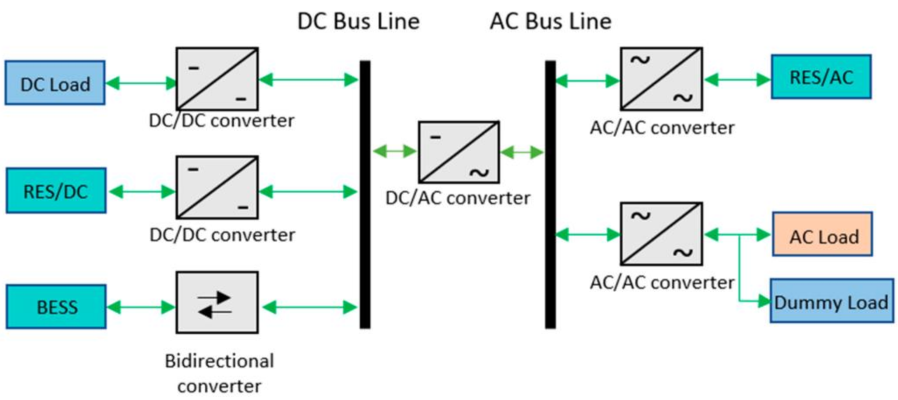


Figure 3. Isolated hybrid network

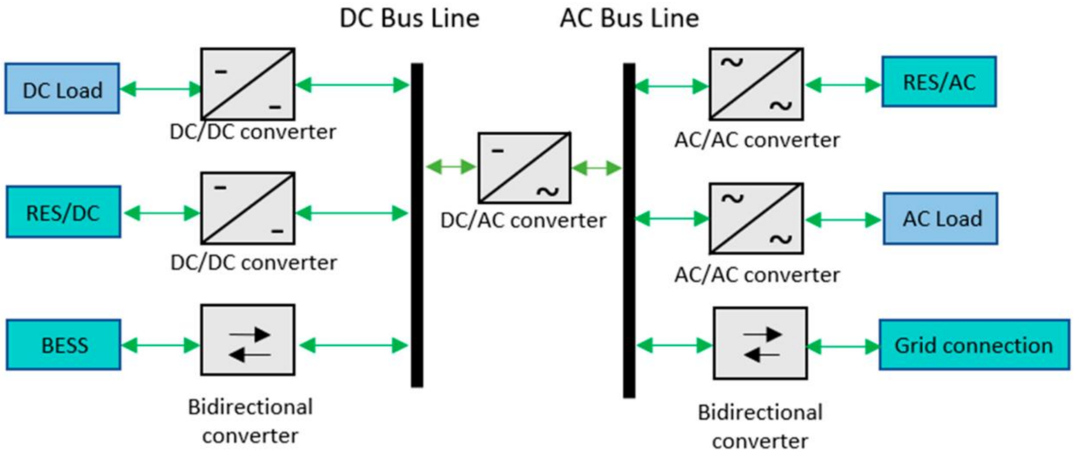


Figure 4. Connected hybrid network

The review indicates that the most commonly used installation mode is an off-grid system, suggesting that most are designed to be installed in locations without access to an electrical grid. Figure 5 shows the energy sources most commonly used in HRES systems in the search conducted.

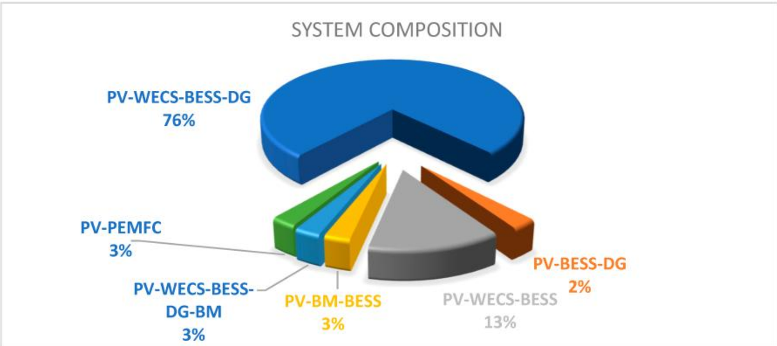


Figure 5. Shows the distributions found in the review, highlighting the configurations that are most studied.

[2] In order to collect electricity from free or ultra-low head water flow, the tidal energy industry needs to develop a new line of environmentally friendly, affordable, and efficient machinery. Although their exact effects on the environment are yet unknown, the negative consequences of tidal barrages are probably much less than those of other power sources. When estimating the amount of resources available, the influence of energy extraction must be taken into account. energy extracted from a potential tidal energy site.

2.2. Energy Storage Sources of an HRES

To increase dependability, the HRES system may incorporate a BESS (battery energy storage system). When there is a strong demand for energy or when weather conditions cause a reduction in the supply of renewable energy, the BESS stores electrical energy produced by renewable sources, such as solar panels or wind turbines, and uses it. To sum up, the BESS is an essential component of the HRES system that guarantees a consistent and sustainable supply of energy. To make it easier to locate publications based on the desired technology. It also identifies every technology utilised in the reviewed articles. Figure 6 shows the types of batteries used in the articles and their percentage of use in the review performed

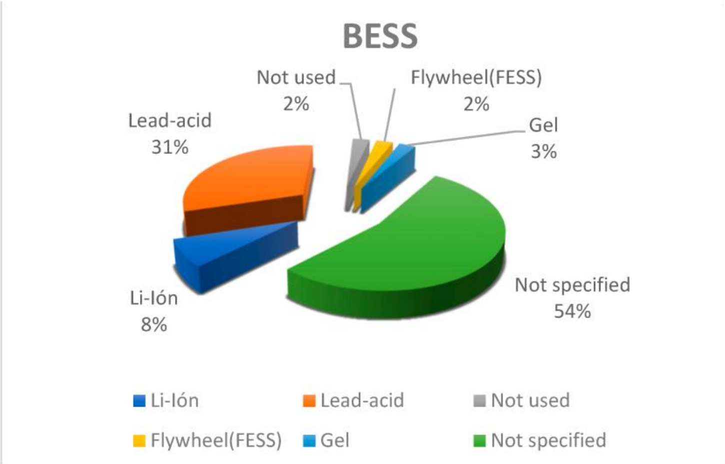


Figure 6. Types of BESSs found in the review

III. Future Trends for the Design and Operation of the Hybrid Energy System

The cost of renewable energy sources is predicted to decline in comparison to the yearly rise in the cost of traditional energy supplies as advances in the research and development of solar and wind technology continue. As a result, this hybrid system will likely be more cost-effective in the future, and its favourable effects on the environment will probably promote its adoption. Furthermore, it is anticipated that the integration of artificial intelligence into energy management would enhance the hybrid system's performance in the near future. Operating costs of the system can be greatly decreased by allocating resources optimally based on load demand and anticipating renewable resources. The performance of modular hybrid power systems is also expected to be enhanced by the use of centralised controllers in conjunction with improved control techniques.

IV. CONCLUSION

Hybrid power systems are regarded as a feasible substitute for grid power delivery. Design strategies need to look for the right mix of important criteria, such cost and system efficiency, in order to optimise the system.

BESS technologies have the potential to be very beneficial for hybrid renewable energy systems. In order to regulate the energy balance between supply and demand by storing energy during off-peak hours at a cheaper cost, a large number of professionals are working to improve the coordination and development of BESS energy storage systems for use in microgrids. While its potential is acknowledged, creating an effective BESS appropriate for microgrid applications is still a significant obstacle.

References

1. Kharrich, M.; Kamel, S.; Abdeen, M.; Mohammed, O.H.; Akherraz, M.; Khurshaid, T.; Rhee, S.-B. Developed Approach Based on Equilibrium Optimizer for Optimal Design of Hybrid PV/Wind/Diesel/Battery Microgrid in Dakhla, Morocco. IEEE Access 2021, 9, 13655–13670.
2. Dipti, D. A Review on Unit Sizing, Optimization and Energy Management of HRES. Int. J. Trend Sci. Res. Dev. 2018, 2, 419–426.
3. Roy, P.; He, J.; Zhao, T.; Singh, Y.V. Recent Advances of Wind-Solar Hybrid Renewable Energy Systems for Power Generation: A Review. IEEE Open J. Ind. Electron. Soc. 2022, 3, 81–104.
4. Nema, P.; Nema, R.K.; Rangnekar, S. A Current and Future State of Art Development of Hybrid Energy System Using Wind and PV-Solar: A Review. Renew. Sustain. Energy Rev. 2008, 13, 2096–2103.
5. Singh, R.; Bansal, R.C. Review of HRESs based on storage options, system architecture and optimisation criteria and methodologies. IET Renew. Power Gener. 2018, 12, 747–760.
6. Ganjei, N.; Zishan, F.; Alayi, R.; Samadi, H.; Jahangiri, M.; Kumar, R.; Mohammadian, A. Designing and Sensitivity Analysis of an Off-Grid Hybrid Wind-Solar Power Plant with Diesel Generator and Battery Backup for the Rural Area in Iran. J. Eng. 2022, 2022, 4966761.
7. Pourbehzadi, M.; Niknam, T.; Aghaei, J.; Mokryani, G.; Shafie-Khah, M.; Catalão, J.P. Optimal operation of hybrid AC/DC microgrids under uncertainty of renewable energy resources: A comprehensive review. Int. J. Electr. Power Energy Syst. 2019, 109, 139–159.

Chapter-6:

Sustainable Development and Application of AI in Eco-Friendly Transportation System Design

Abhishek Poddar[1]

[1]Swami Vivekananda University

abhishekp@svu.ac.in

Sustainable Development and Application of AI in Eco-Friendly Transportation System Design

Abhishek Poddar[1]

[1]Swami Vivekananda University

abhishekp@svu.ac.in

Abstract

Sustainable transportation plays a vital role in reducing environmental impact and enhancing urban liveability. The application of Artificial Intelligence (AI) in the design of eco-friendly transportation systems has gained significant traction due to its ability to optimize performance, reduce emissions, and enhance energy efficiency. This review explores the potential of AI in the development of sustainable transportation, including traffic management, electric and autonomous vehicles, smart infrastructure, and energy optimization. It examines the role of AI-driven tools in reducing carbon footprints, enabling intelligent transportation systems, and facilitating the transition to greener mobility solutions. The paper also addresses current challenges and future opportunities in using AI to design eco-friendly transport networks.

1. Introduction

Transportation is a critical sector responsible for a significant proportion of global greenhouse gas emissions, primarily due to reliance on fossil fuels. As urbanization increases, the demand for mobility continues to grow, exacerbating the environmental impact of traditional transportation systems. To combat these challenges, sustainable transportation systems must be designed to reduce carbon emissions, improve energy efficiency, and minimize resource consumption. This requires the integration of innovative technologies, including Artificial Intelligence (AI), to optimize the performance and sustainability of transport networks.

AI is revolutionizing the way transportation systems are designed and managed. By processing vast amounts of data in real time, AI enables the optimization of traffic flows, energy use, and vehicle performance. AI-driven solutions are helping cities and transportation planners design more eco-friendly systems by reducing congestion, improving fuel efficiency, and facilitating the transition to electric and autonomous vehicles. This paper discusses the role of AI in various aspects of eco-friendly transportation system design, including intelligent traffic management, smart infrastructure, electric mobility, and the integration of renewable energy sources into transportation networks.

2. AI in Traffic Management for Sustainable Transportation

One of the most significant ways AI contributes to sustainable transportation is through intelligent traffic management. Traffic congestion not only wastes time and resources but also contributes to air pollution and fuel consumption. AI-powered traffic management systems use real-time data from sensors, cameras, and GPS devices to monitor traffic patterns, predict congestion, and optimize traffic flow.

AI algorithms analyze traffic data to predict peak traffic hours and adjust signal timings accordingly. This reduces idling time at intersections, lowering fuel consumption and emissions. Additionally, AI can optimize public transportation routes and schedules, ensuring that buses and trains operate efficiently and reduce unnecessary trips (Tang et al., 2019). Autonomous vehicles (AVs) integrated with AI systems can also play a crucial role in traffic management by communicating with each other and adjusting routes to avoid congested areas.

Moreover, AI-based systems can prioritize eco-friendly transport modes, such as bicycles and electric vehicles (EVs), by creating dedicated lanes or adjusting traffic signals to favor these modes. This encourages the use of low-emission vehicles and reduces the overall environmental impact of transportation (Pangbourne et al., 2020).

3. AI in Electric and Autonomous Vehicle Design

The development and adoption of electric vehicles (EVs) are essential to achieving a sustainable transportation system. AI plays a key role in optimizing the performance, efficiency, and sustainability of EVs. Machine learning algorithms are used to optimize battery management systems, ensuring that EV batteries are charged and discharged efficiently, extending battery life, and improving energy consumption.

AI also enhances the design of autonomous vehicles (AVs), which are expected to play a significant role in future transportation systems. AVs rely on AI for decision-making, enabling them to navigate traffic, avoid obstacles, and operate efficiently. The integration of

AI into AV design improves fuel efficiency by optimizing driving patterns, reducing unnecessary acceleration and braking, and enabling smoother traffic flow (Liu et al., 2021).

Furthermore, AI facilitates the development of vehicle-to-everything (V2X) communication systems, where vehicles can communicate with each other and with infrastructure to improve traffic safety and efficiency. V2X systems enable AVs to share information about road conditions, traffic patterns, and accidents, allowing for real-time adjustments that reduce congestion and emissions.

4. AI in Smart Infrastructure Design

AI is also transforming the design of transportation infrastructure to make it more sustainable and eco-friendlier. Smart infrastructure refers to the use of AI and digital technologies to optimize the performance and efficiency of transportation systems. For instance, AI can be used to manage energy consumption in street lighting by adjusting the brightness based on traffic density and time of day, thus reducing electricity use (Sun et al., 2020).

AI is also crucial in designing and managing smart grids that integrate renewable energy sources, such as solar and wind, into transportation networks. This is especially important for charging infrastructure for electric vehicles, where AI algorithms can optimize charging times and locations to balance the demand for electricity and ensure that charging stations are powered by renewable energy.

Furthermore, AI can enhance the maintenance of transportation infrastructure. AI-driven predictive maintenance systems can monitor roads, bridges, and railways for signs of wear and tear, allowing for timely repairs that extend the lifespan of infrastructure and reduce the environmental impact of construction and repairs (Sinha et al., 2021).

5. AI in Energy Optimization and Sustainable Mobility

A key factor in the sustainability of transportation systems is energy efficiency. AI can optimize energy use in various ways, from improving the fuel efficiency of vehicles to managing the distribution of renewable energy. For example, AI algorithms can optimize the routes of delivery trucks to minimize fuel consumption by considering traffic conditions, road gradients, and vehicle loads (Ghaffarianhoseini et al., 2021). In the context of public transportation, AI can manage energy use by optimizing train schedules and adjusting speeds to minimize energy consumption.

Additionally, AI can integrate renewable energy sources into transportation systems. For instance, AI can manage the charging of electric vehicles by ensuring that they are charged during periods of low electricity demand or when renewable energy generation is high. This helps reduce reliance on fossil fuels and lowers the carbon footprint of transportation systems.

AI also plays a role in optimizing shared mobility solutions, such as ride-sharing and bike-sharing programs, which contribute to the reduction of individual vehicle use and traffic congestion. AI can predict demand for shared mobility services based on historical data and real-time conditions, allowing operators to allocate resources efficiently and reduce unnecessary trips (Banerjee et al., 2019).

6. Case Studies

Several cities around the world are leveraging AI to create more sustainable transportation systems. One example is the city of Amsterdam, which uses AI-powered traffic management systems to optimize traffic flow and reduce emissions. The system uses data from sensors and cameras to predict congestion and adjust traffic signals accordingly. Additionally, the city has implemented AI-driven energy management systems that integrate renewable energy sources into the electric vehicle charging infrastructure, ensuring that EVs are charged with clean energy (City of Amsterdam, 2021).

In another case, the city of Singapore has adopted an AI-powered public transportation system that optimizes bus and train schedules based on real-time demand. The system uses AI algorithms to predict passenger demand and adjust routes and schedules accordingly, reducing unnecessary trips and minimizing energy consumption. Singapore has also integrated AI into its traffic management system, using real-time data to optimize signal timings and reduce congestion (Chin, 2020).

7. Challenges and Future Directions

While AI holds great promise for the design of sustainable transportation systems, there are several challenges that must be addressed. One of the primary challenges is data availability and quality. AI systems rely on large amounts of data to make accurate predictions and optimizations, but data on traffic patterns, vehicle performance, and energy use is often incomplete or inconsistent. Furthermore, there are concerns about data privacy and security, particularly in the context of autonomous vehicles and V2X communication systems.

Another challenge is the integration of AI into existing transportation infrastructure. Many cities have legacy systems that are not compatible with AI-driven technologies, and upgrading these systems can be costly and time-consuming. Additionally, there are concerns about the social and ethical implications of AI, particularly in terms of job displacement and equity in access to sustainable transportation solutions.

Despite these challenges, the future of AI in sustainable transportation is bright. Continued advancements in AI technology, combined with growing awareness of the need for sustainability, are expected to drive further innovation in eco-friendly transportation systems. Future research should focus on improving the accuracy and reliability of AI algorithms, addressing data privacy concerns, and ensuring that AI-driven solutions are accessible to all members of society.

8. Conclusion

AI is playing an increasingly important role in the design of eco-friendly transportation systems. From intelligent traffic management and electric vehicle optimization to smart infrastructure and energy efficiency, AI is helping to reduce the environmental impact of transportation while improving performance and reliability. By integrating AI into the design and management of transportation networks, cities can reduce congestion, lower emissions, and create more sustainable mobility solutions.

However, there are still challenges that need to be addressed, including data availability, system integration, and ethical concerns. As AI technology continues to evolve, it is expected to play a critical role in shaping the future of sustainable transportation, enabling the transition to greener, more efficient, and more equitable mobility systems.

References

Banerjee, A., Hildreth, R., & Thakur, M. (2019). AI and the future of shared mobility: The role of intelligent algorithms in sustainable transportation. Journal of Urban Mobility, 24(2), 112-124.

Chin, H. (2020). AI-powered public transportation in Singapore: Improving efficiency and sustainability. Smart Cities Journal, 6(3), 45-56.

City of Amsterdam. (2021). AI-driven sustainable transportation initiatives. Amsterdam Smart City Reports, 18(1), 56-69.

Ghaffarianhoseini, A., Berardi, U., & Alwaer, H. (2021). The application of AI in optimizing energy use in transportation systems. Journal of Sustainable Mobility, 32(4), 198-213.

Liu, J., Wu, T., & Zhang, Y. (2021). AI-driven design of electric and autonomous vehicles: Enhancing sustainability. Transportation Research Part C, 104, 89-101.

Pangbourne, K., Mladenovic, M., Stead, D., & Milakis, D. (2020). The role of AI in eco-friendly traffic management. Urban Sustainability Review, 14(2), 91-105.

Sinha, S., Gupta, R., & Basu, K. (2021). Smart infrastructure and AI: Enhancing the sustainability of transportation networks. Journal of Infrastructure Research, 22(3), 78-89.

Sun, X., Ma, Y., & Li, Z. (2020). AI in smart infrastructure design: Optimizing energy use and sustainability. Journal of Engineering Sustainability, 16(1), 31-42.

Chapter-6:

Dynamic seismic analysis of multi-storied buildings having different heights for all seismic zones in India

Rejina Yasmin[1], Abir Sarkar[2]

[1] Research Scholar, Department of Civil Engineering,

Swami Vivekananda University, Kolkata 700121, INDIA

rejinayasmin3@gmail.com

[2] Asst. Prof., Department of Civil Engineering,

Swami Vivekananda University, Kolkata 700121, INDIA

abirs@svu.ac.in

Dynamic seismic analysis of multi-storied buildings having different heights for all seismic zones in India

Rejina Yasmin[1], Abir Sarkar[2]

[1] Research Scholar, Department of Civil Engineering,
Swami Vivekananda University, Kolkata 700121, INDIA
rejinayasmin3@gmail.com
[2] Asst. Prof., Department of Civil Engineering,
Swami Vivekananda University, Kolkata 700121, INDIA
abirs@svu.ac.in

Abstract. This study examines the application of the Response Spectrum Method across seismic zones in India, ranging from low to critical seismic regions. In the realm of civil engineering, constructing buildings of varying heights necessitates a paramount focus on ensuring structural safety, serviceability, and durability. With the growing significance of seismic events in modern times, safeguarding structures against potential damage caused by seismic excitations becomes a critical concern. The extent of seismic damage inflicted upon structures hinges on several factors, including building height, seismic zone classification, seismic resistance techniques, and soil characteristics. The relationship between earthquake effects and structure height is particularly noteworthy, as seismic waves can alter ground motion, thereby influencing structural integrity. This study delves into the performance of structures of diverse heights situated in different seismic zones. It places specific emphasis on the Response Spectrum Method, a seismic resistance technique known for enhancing structural behavior when confronted with lateral forces during seismic events. By analyzing the effectiveness of this method across varying structural heights in different seismic zones, this research contributes to a deeper understanding of seismic resilience in the context of Indian construction practices.

Keywords: Seismic Zones, Storey displacement, Base Shear, Base moment, SAAP2000 software, Response spectrum method.

1. **Introduction**

Throughout history, earthquakes have claimed countless lives and inflicted extensive property damage. The sheer force of seismic waves has the potential to induce ground motion leading to building collapses, landslides, tsunamis, and volcanic activities. A stark reminder of this vulnerability is the recent 6.4 magnitude earthquake that struck Assam, India, on April 28, 2023, resulting in two fatalities, and at least 12 injuries, with buildings collapsing at the epicenter. This region falls within the highly seismic Hazard Zone V. These incidents underscore the paramount importance of implementing earthquake-resistant design principles in structures to mitigate casualties and damage. Structural engineers have tirelessly endeavored to reduce lateral loads and enhance structural rigidity through mechanisms such as "moment resisting frames." These frames aim to bolster a building's seismic resistance, particularly during major earthquakes. However, the effectiveness of these techniques varies with factors such as building height, seismic zone classification, and the inherent soil characteristics of the location. India's seismic zoning map classifies the country into four seismic zones (Zone II, III, IV, and V), with Zone V experiencing the highest level of seismicity. These zones are outlined in the Indian standard code IS:1893, part-1, 2016. This study encompasses all seismic zones to provide insights into structural performance under varying seismic excitations.

This research focuses on the performance of structures of differing heights across all seismic zones, with a specific emphasis on the utilization of the Response Spectrum Method. Understanding the interaction between building height and seismic zones in India is crucial in advancing our knowledge of structural resilience. The numerical analysis in this study is conducted using SAP2000 software, known for its capabilities in structural analysis. A multi-storey building is analyzed, considering critical lateral load conditions, and designed as a Special Moment Resisting Frame (SMRF) to enhance performance. AutoCAD software is employed for floor plan creation. Response Reduction Factor, R, as per IS 1893, part-1, 2016, guides the structural design. The study evaluates storey displacement, base shear, and base moment to gauge structural response.

The primary aim of this study is to conduct seismic analysis on G+5, G+10, G+15, and G+20 storey residential buildings across all seismic zones in India using SAP2000, v24 software. The objectives encompass dynamic analysis of buildings with varying heights, improving seismic resistance compared to conventional construction, adherence to IS 1893-2016 part-I criteria, ensuring safety, stability, and serviceability during earthquakes, creating awareness of seismic effects, and demonstrating improved building response under dynamic loading conditions. This research aims to enhance our understanding of the seismic behavior of buildings of different heights in various seismic zones, ultimately contributing to safer and more resilient structural design practices.

2. Literature review

The literature review concentrated on seismic forces and their influence on the quality of life, as explored by researchers who have analyzed seismic forces across different earthquake zones. These authors also elucidated the investigations carried out to mitigate or manage seismic effects. Below, we delve into these research papers to acquire insights into seismic responses and gain an understanding of seismic analysis from previous studies.

Dr. Nagesh, Yash Dehankar (May, 2022): The paper involves the comparative study of Seismic analysis of different heights building on different types of soil using Base Isolation technique (for G+10, G+15, G+20, G+25). The comparative study focuses on the behavior of different height of structure, Earthquake Zone, and type of Soil with Base Isolation techniques (Codes are: IS456:2000; IS1893:2016 and IS 13920:1993). Friction Isolator, Triple pendulum Isolator, Lead Rubber bearing Isolator is used in Base Isolation techniques. There has Friction Isolator which has better results than other base Isolator. In case of soft soil Frictional Isolator is better but in case of other types of soil frictional Isolator and Triple pendulum Isolator shows the same result. For the analysis of Base Isolation technique has been used and modeling of structures has done by ETABS.

In June 2022, Shaik Akhil Ahamad and K.V. Pratap conducted a dynamic analysis of a G+20 multi-storied building using shear walls located in various positions within different seismic zones. They employed the ETABS software for this investigation, focusing on the comparative behavior of braced frame buildings through dynamic analysis (according to IS 13920:1993 and IS: 875-1987 standards). The study utilized the Response Spectrum Method.

The findings revealed that incorporating a braced system in the structure is advantageous for resisting seismic waves, as it effectively reduces displacement, axial forces, and bending moments in columns. Across all seismic zones in India, the study observed higher maximum displacement values in seismic zone V. It was also noted that introducing uniform stiffness in the structure can further mitigate displacement. In the case of soft soil, structures featuring symmetrically placed shear walls demonstrated superior performance compared to those without shear walls. Vinay Danam (Oct, 2015): The paper has done lateral load analysis of multistoried RCC building (G+10) by considering 4 models. In the first model is without providing any shear wall, in the second model has coupled type with openings and the third model has a rectangle type shear wall at four corners, and the fourth model corner core type shear wall system has done by SAP2000 software. This study mainly focused on seismic forces, lateral displacement and shear wall system. In this paper G+10 storey building analyzed with different types of shear walls. Maximum earthquake intensity area (Zone IV, Zone V) where four corners and centroid shear wall can reduce the deflection of the building. Also, it can reduce the shear force and bending moment of the building. It is observed that in Zone III, rectangular type shear wall and in Zone II coupled type shear wall is more suitable.

In September 2013, A.E. Hassaballa, Fathelrahman M. Adam, and M.A. Ismaeil used STAAD PRO software to analyze a G+25 storey reinforced concrete building's seismic response via the Response Spectrum Method. Their study aimed to assess displacements, stresses, and seismic hazards. The results showed excellent column and beam deflection performance. Exterior columns had a greater seismic impact than interior ones, and ground floor columns experienced compression stresses 1.2 to 2 times higher than tensile stresses. Beams exhibited nearly equal maximum tension and compression values during seismic analysis.

Mr. Murat Saatcioglu and JagMohan Humar (23 April 2003): They studied dynamic analysis of (G+5, G+10, G+15) building for earthquake resistance design by SAP2000 software. This analysis is done by linear dynamic method. The paper provides an overview of dynamic analysis, elastic analysis, fundamental period, seismic design, structural analysis and structural design. The comparative study focuses on the behavior of braced frame building with the help of dynamic analysis (IS 13920:1993, IS: 875-1987). The result gives better if we provide Braced system in the structure to reduce displacement, axial force and bending moment in columns.

E. Pavan Kumar, A. Naresh, M. Nagajyothi, and M. Rajasekhar (November, 2014) conducted earthquake analysis on a G+15 multi-storied residential building using the Response Spectrum Method. Their study compared the seismic behavior of Ordinary Moment Resisting Frames (OMRF) and Special Moment Resisting Frames (SMRF) through STAAD.PRO V8i software.

Vinay Mantha and S.S.Sanghai (June, 2016) conducted a study comparing seismic and non-seismic analysis of a G+17 storey building using SAP2000. They employed the Equivalent Static Method with the goal of minimizing structural damage during seismic events in a cost-effective manner. The study focused on analyzing maximum shear forces and bending moments, revealing significantly increased values in seismic analysis compared to non-seismic analysis.

Dr. Sachin Balkrishna Mulay, Dr. Jyotiprakash G. Nayak, and Mr. Rahul Tarachand Pardeshi (Dec, 2022) conducted research on the analysis and design of shear walls and storey drift in a high-rise building under seismic excitations. They utilized I-shaped shear walls and employed the Response Spectrum Method via ETABS software. The objective was to determine the optimal location for shear walls to enhance resistance against lateral forces in seismic zone IV. The study compared two building conditions: one with shear walls, which effectively resisted lateral forces, and another without shear walls, which failed to provide sufficient lateral force resistance.

K. Supreem, N. Ragunath, S. Madhu (Oct, 2022): In the research, there has seismic analysis of G+15 storey building has done by using Response Spectrum Analysis method by using SAP2000 software. The comparative study is focused on the response spectrum method and Time period method for seismic analysis. In Time period method results more. In time period method results show that to check the Time period of structure, should be 2.7 sec for regular structure.

K.Ramakrishna Reddy, DR. S. Vijaya Mohan Rao (Nov, 2016): The paper involves the comparative study of Seismic analysis of different heights of building using Time History method (for G+15, G+20, G+25). The comparative study focuses on the behavior of different height of structure, Earthquake Zone, and type of Soil. The response spectrum method has been used for this study. Response spectrum method has been used for this study. To resist seismic wave it is better if we provide Shear wall in the structure to reduce displacement, axial force, and bending moment in columns. In all the seismic zones of India, maximum displacement values are found to be higher in seismic zone v. It is better if we provide uniform stiffness in the structure to reduce displacement. In case of soft soil, the structure with shear walls placed symmetrically will give better results as compared to the structure without shear walls.

Dr. B. Anil, N.V.S.S.Raju (July, 2012): The paper involves the comparative study of response spectrum analysis for (G+5, G+10, G+15, G+20) storied building. Comparative study on the displacement of different height building under different soil condition is done. The comparative study focuses on the behavior of different height of structure, Earthquake Zone, and type of Soil. Response spectrum analysis and Time history analysis method has been used for this study. To resist seismic wave it is better if we provide Shear wall in the structure to reduce displacement, axial force, and bending moment in columns. Maximum displacement is found in the soil of Sathupally than Eluru and Guntur. In response spectrum analysis, it is better if we provide shear wall and also if we provide shear wall symmetrically.

Dheeraj Bothra, Yashish Rathi (Feb, 2022): The paper is about the seismic analysis of high-rise building with vertical irregularities. In this research, there have (G+30, G+30 with vertical irregularity) multi-storied building is analyzed by using ETABS software. In this paper behavior, seismic response, time period, storey drift, shear force, and axial force is compared with normal building and building with vertical irregularities.

Mohsin Aakib Shamim Akhtar (Feb, 2022): The paper involves dynamic seismic analysis of multi-storey buildings in seismic zone V by using STAAD.PRO software. In this research, behavior, seismic response, time period, storey drift, shear force, and axial force is compared with normal building and building with double cross type bracing.

Kassem Trabolsi (Nov, 2020): The paper is about the study of the effect of soil structure interaction of a high rise building on a raft foundation by using SAP2000 software. The objective of the study is to observe the effect of soil structure interaction on the response of high-rise buildings with raft foundations. In this paper building on different types of soil with seismic excitation has been observed.

3. **Methodology**

The study focuses on the seismic analysis of a multi-storied building with varying heights. However, seismic analysis encompasses different approaches. The Equivalent Static Method proves adequate for smaller building structures in terms of seismic resistance analysis. For taller structures, it necessitates consideration of more than two modes and the calculation of mass weights for each mode to withstand lateral seismic loads. This method is unsuitable for analyzing high-rise structures. Conversely, seismic analysis requires specific location considerations. The Time History Method encounters challenges in obtaining seismic records for every location within a seismic zone area.

In contrast, the Pushover Method faces limitations in accounting for variations in dynamic properties and nonlinear responses caused by changes in stiffness and strength during load cycles. Consequently, the Response Spectrum Method is employed to address these challenges. This method enables the analysis of displacement and member forces within the structure and can calculate maximum displacement values and member forces for each mode of earthquake shaking using a design spectrum.

4. **Problem Statement**

The SAP2000 software is used for developing 3D modeling and analysis. The lateral loads that are applied on the different heights of buildings are based on the Indian standard codes. The study is performed for different seismic zones in India as per IS 1893:2016 (part 1).

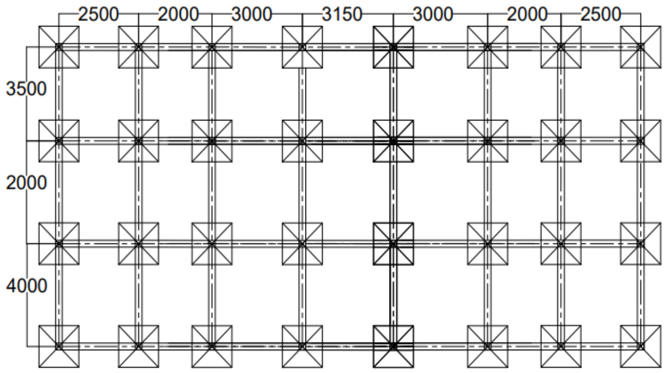


Fig. 1. Flow chart of methodologies

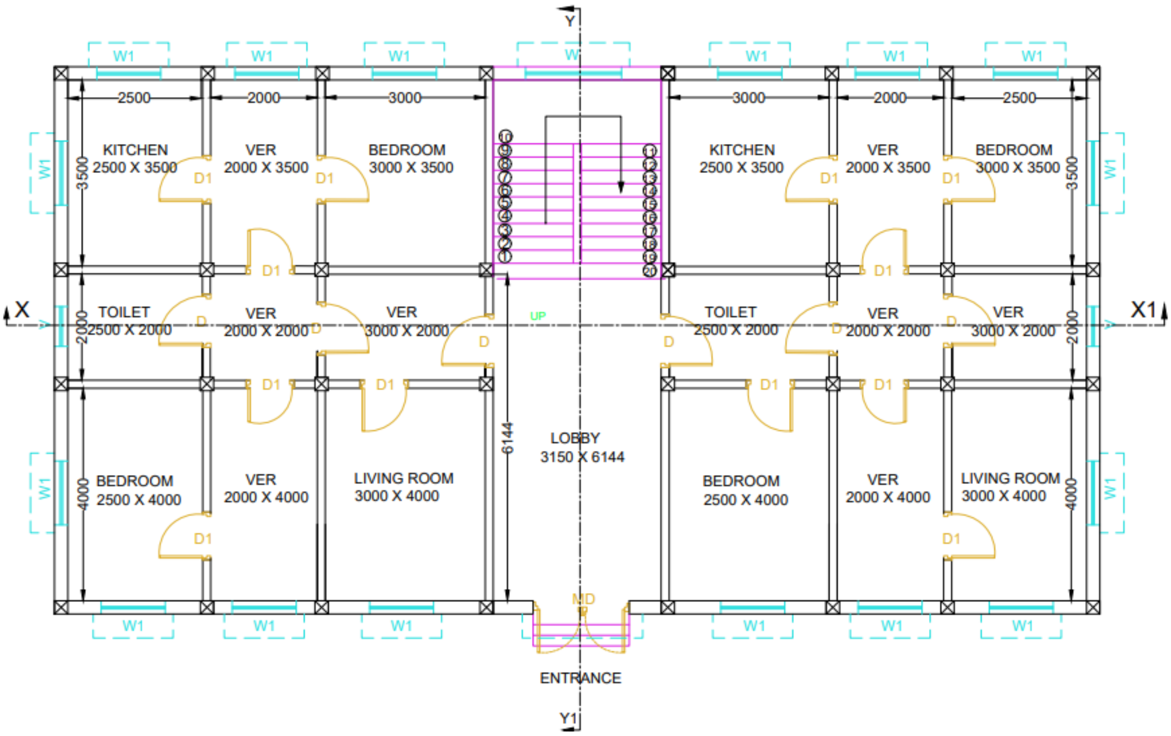


Fig. 2. Column & beam positions

Table-2: Building Specification

Component	Value
Structure	SMRF
Number of model	16
Each Storey height	G+5,G+10,G+15,G+20
Type of building	Residential
Seismic Zone	Zone II, III, IV, V (As per IS 1893:2016(part1))

Table-3: Material properties

Component	Value
Grade of concrete	M25, M30
Grade of steel	Fe500
Density of reinforced concrete	25 KN/m2
Density of steel	78.5 KN/m2

Table-4: Member properties

Component	Value
Beam size	300mm X 250mm
column size	Rectangular column: 350mm X 300mm Square column: 300mm X 300mm
Slab thickness	150mm

Table-5: Seismic properties

Component	Value
Live loads	2KN/m2, 3KN/m2, 1.5 KN/m2 and 0.75 KN/m2 (as per IS 875(part2))
Zone factor(Z)	0.10, 0.16, 0.24, 0.36 (as per IS: 1893:2016; table-3(part-1, cl-6.4.2))
Importance factor(I)	1 (as per IS:1893(part-1):2016,table-8)
Response reduction	5

factor	(as per IS:1893(part-1):2016,table-9)
Soil type	II (medium soil) (as per IS:1893(part-1):2016,table-4)
Damping factor	0.05 (as per IS: 1893:2016; (part-1, cl-7.2.4))

The 3D model of the plan

- Model 1: G+5 storey RC SMRF building in Seismic zone II
- Model 2: G+5 storey RC SMRF building in Seismic zone III
- Model 3: G+5 storey RC SMRF building in Seismic zone IV
- Model 4: G+5 storey RC SMRF building in Seismic zone V
- Model 5: G+10 storey RC SMRF building in Seismic zone II
- Model 6: G+10 storey RC SMRF building in Seismic zone III
- Model 7: G+10 storey RC SMRF building in Seismic zone IV
- Model 8: G+10 storey RC SMRF building in Seismic zone V
- Model 9: G+15 storey RC SMRF building in Seismic zone II
- Model 10: G+15 storey RC SMRF building in Seismic zone III
- Model 11: G+15 storey RC SMRF building in Seismic zone IV
- Model 12: G+15 storey RC SMRF building in Seismic zone V
- Model 13: G+20 storey RC SMRF building in Seismic zone II
- Model 14: G+20 storey RC SMRF building in Seismic zone III
- Model 15: G+20 storey RC SMRF building in Seismic zone IV
- Model 16: G+20 storey RC SMRF building in Seismic zone V

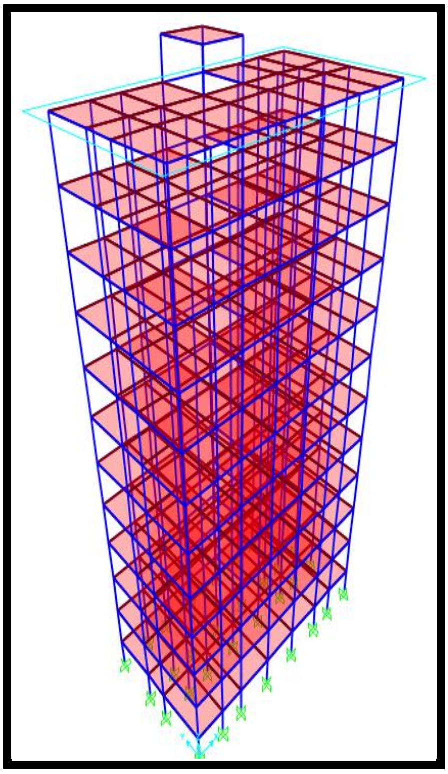


Fig. 4. 3D model for G+10 storey

To find out the performance of the different heights of the RCC building, the comparative study about storey displacement, frequency, time period, base shear and moment with the help of linear analysis by SAP2000 software. Four different heights of models were studied for medium soil in low seismic zone to critical seismic zone.

2. **Response spectrum analysis**

Conducting a response spectrum analysis aims to ascertain the seismic forces' distribution across each floor of a multi-story residential building and its various lateral load-resisting components.

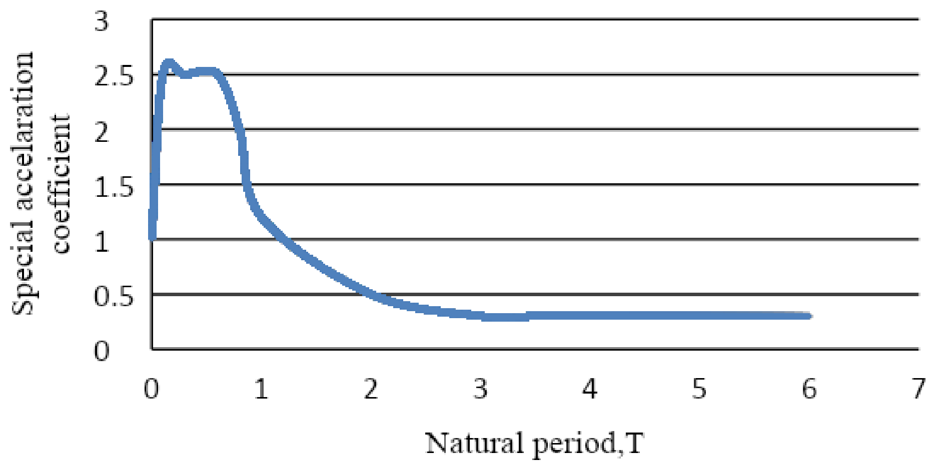


Fig. 5. Design acceleration coefficient (Sa/g) vs. Time period (T) for Medium soil (Source: IS: 1893, 2016 (part-1, Fig.2))

The SAAP2000 software utilizes the following bellow procedure to generate the lateral seismic loads to the building.

1] Creating grid points and generating the structure

2] Defining and assigning of properties

3] Assigning of supports

4] Defining approximate fundamental natural period Ta of oscillation in second,

$Ta=0.075h^{0.75}$ (As per IS: 1893 (part-1):2016; cl-7.6.2)

For G+5 storey building, $Ta= 0.075 X 22^{0.75} = 0.76$ cycle/sec

For G+10 storey building, $Ta= 0.075 X 37^{0.75} = 1.13$ cycle/sec

For G+15 storey building, $Ta= 0.075 X 52^{0.75} = 1.45$ cycle/sec

For G+20 storey building, $Ta= 0.075 X 67^{0.75} = 1.76$ cycle/sec

5] Defining load pattern and load combination

This analysis has been done by horizontal X and Y to resist lateral seismic forces. Out of all the load combinations analyzed, the following seismic load combinations are given below,

1.2(DL+LL±RSX)

1.2(DL+LL±RSY)

1.5(DL±RSX)

1.5(DL±RSY)

0.9DL±1.5RSX

0.9DL±1.5RSY

6] Assigning of dead loads

For Slab load

Floor load= Slab thickness X concrete density

= 0.15 X 25 = 3.75 Kn/m2

For floor finish load = 1 Kn/m2

For wall load

External wall load= wall thickness X unit weight of brick X (total height – beam depth)

= 0.25 X 20 X (3.1-0.3)

= 14 KN/m

Internal wall load= wall thickness X unit weight of brick X (total height – beam depth)

= 0.15 X 20 X (3.1-0.3)

= 8.4 KN/m

Parapet wall load= wall thickness X unit weight of brick X height of parapet wall

= 0.125 X 20 X 1.2

= 3 KN/m

7] Assigning of live loads

The live loads or imposed loads to be taken in the residential buildings have been given in IS 875 (part-2) -1987. The live loads which are used in this analysis, are: 2KN/m2 (for rooms and floors), 3KN/m2 (for the staircase), 1.5 KN/m2 (for the accessible roof) and 0.75 KN/m2 (for the non-accessible roof).

8] Assigning of seismic loads

9] Assigning of load combinations

10] Analysis of G+5, G+10, G+15, G+20 storey buildings.

4. Results and Discussion

Data obtained from the Saap2000 software has been compiled in various formats, including tables and figures. These visual representations facilitated the comparison of results across different building heights within various seismic zones in India. The figures and tables below illustrate the analysis of maximum displacement, base shear, base moment, fundamental time period, and frequency, all of which were examined to assess the lateral stability of the building.

1. **Joint Displacements**

Table-6: Maximum displacement obtained from SAP2000

Seismic Zones	Building Height	RSX (mm)	RSY (mm)
Zone-II	G+5	8.2	8.8
	G+10	14.3	19.2
	G+15	15.2	20.5
	G+20	40.6	54.0
Zone-III	G+5	13.1	14.1
	G+10	23.0	30.0
	G+15	24.3	32.8
	G+20	65.1	86.5
Zone-IV	G+5	19.7	21.2
	G+10	36.4	49.2
	G+15	54.0	73.0
	G+20	97.6	129.0
Zone-V	G+5	29.5	31.8
	G+10	51.8	69.3
	G+15	78.0	97.0
	G+20	146.0	194.0

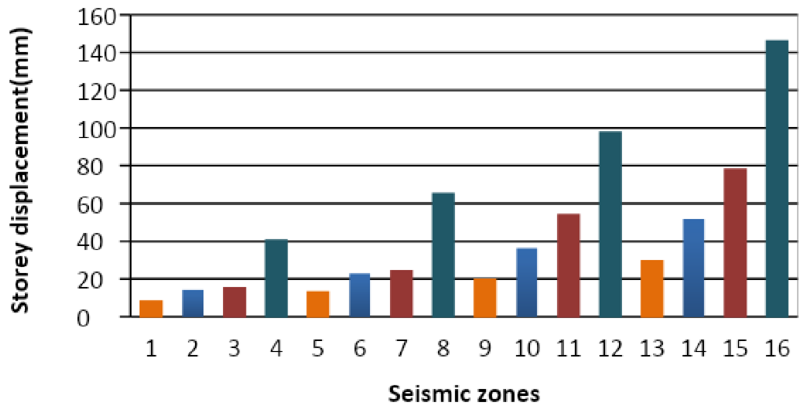


Fig. 6. Comparison of Maximum displacement of different building heights vs. seismic zones along X direction

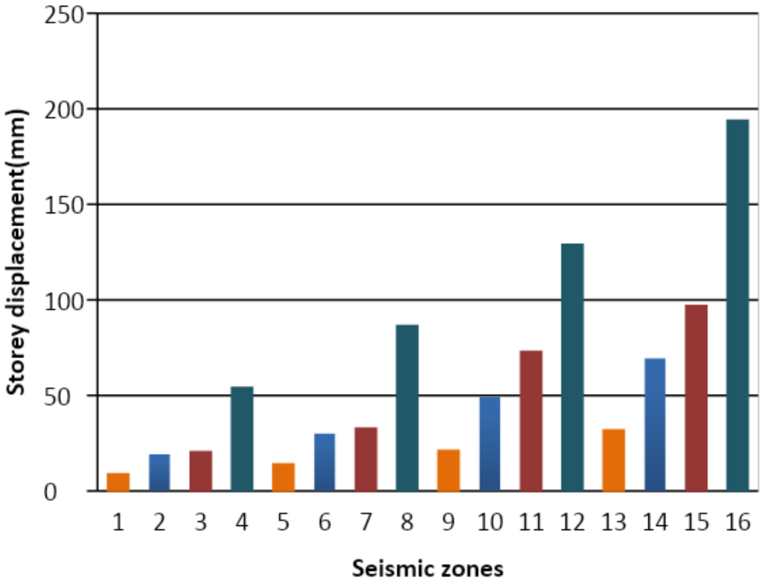


Fig. 7. Comparison of Maximum displacement of different building height vs. seismic zones along Y direction

2. **Base Reactions**

Table-7: Maximum base shear obtained from SAP2000

Seismic Zones	Building Height	RSX (KN)	RSY (KN)
Zone-II	G+5	131	131
	G+10	215	370
	G+15	271	425
	G+20	280	597
Zone-III	G+5	202	203
	G+10	345	351
	G+15	434	477
	G+20	460	629
Zone-IV	G+5	485	468
	G+10	518	580
	G+15	621	629
	G+20	637	670
Zone-V	G+5	728	728
	G+10	777	780
	G+15	978	998
	G+20	1015	1021

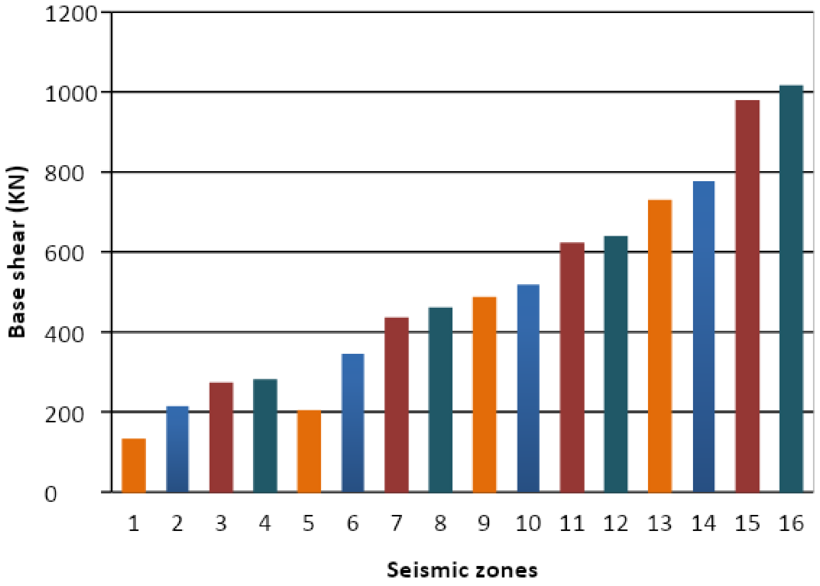


Fig. 8. Comparison of Maximum base shear of different building height vs. seismic zones along X direction

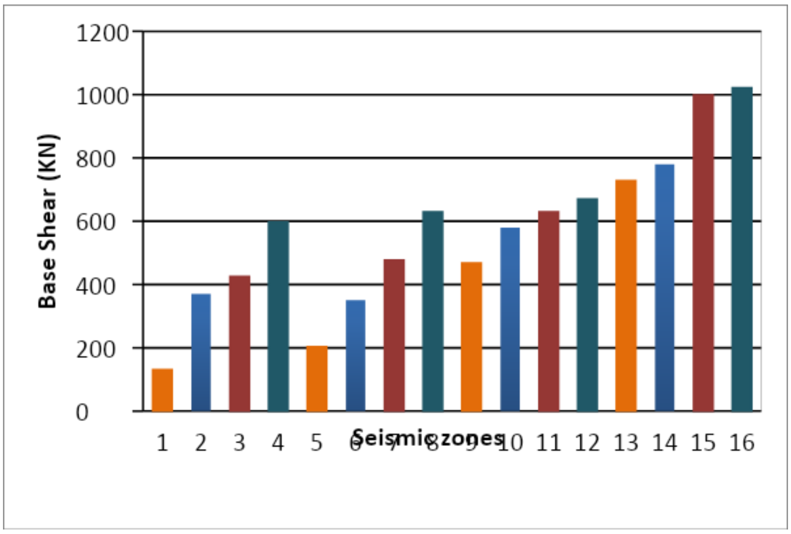


Fig. 9. Comparison of Maximum base shear of different building height vs. seismic zones along Y direction

Table-8: Maximum base moment obtained from SAP2000

Seismic Zones	Building Height	RSX (KN.m)	RSY (KN.m)
Zone-II	G+5	82	82
	G+10	102	108
	G+15	118	118
	G+20	159	163
Zone-III	G+5	105	109
	G+10	180	183

	G+15	181	181
	G+20	225	270
Zone-IV	G+5	157	197
	G+10	210	225
	G+15	225	225
	G+20	251	290
Zone-V	G+5	210	210
	G+10	246	267
	G+15	259	305
	G+20	301	324

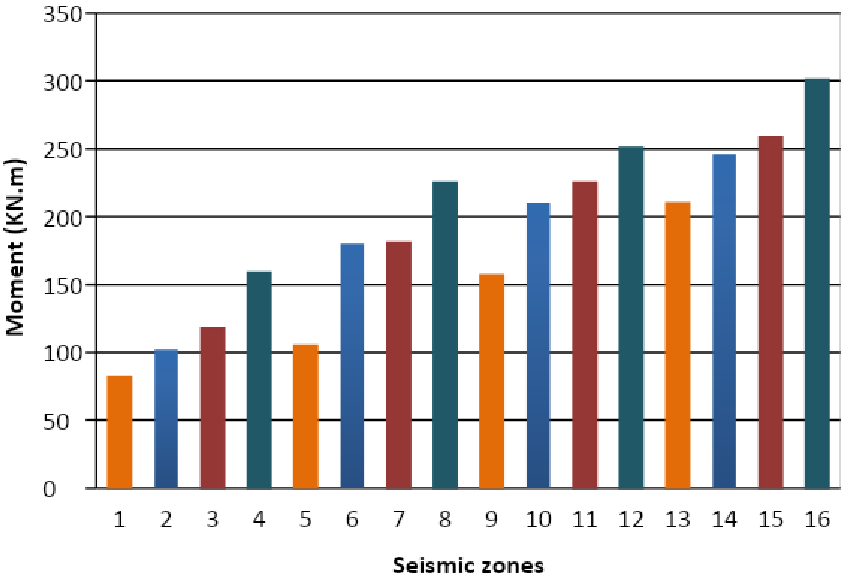


Fig. 10. Comparison of Maximum base moment of different building heights vs. seismic zones along X direction

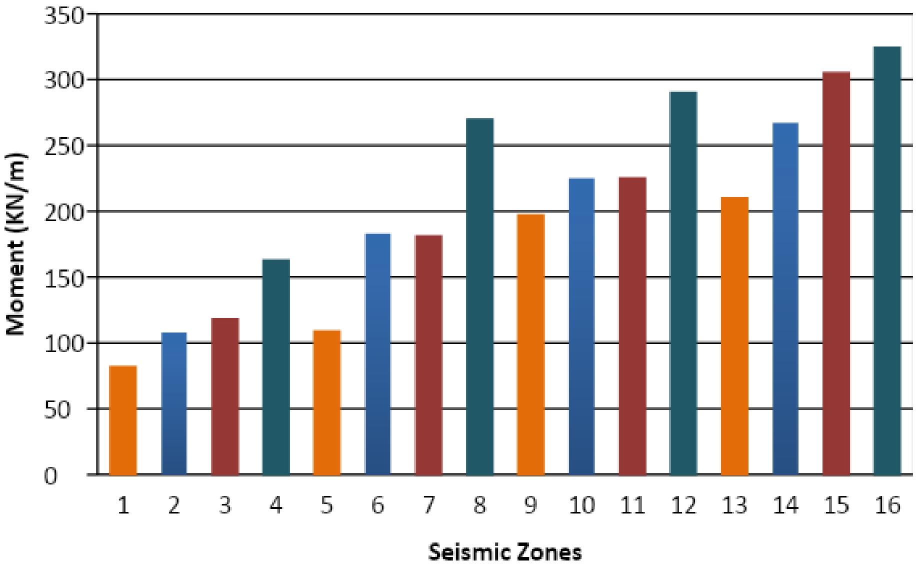


Fig. 11. Comparison of Maximum base moment of different building height vs. seismic zones along Y direction

3. Periods and Frequencies

Table-9: Time period & Frequencies are obtained from SAP2000

Seismic Zones	Building Height	Time Period (Sec)	Frequency (Cycle/sec)
Zone-II	G+5	1.67	0.59
	G+10	3.3	0.30
	G+15	3.3	0.30
	G+20	6.12	0.16
Zone-III	G+5	1.68	0.60
	G+10	3.3	0.30
	G+15	3.2	0.30
	G+20	6.12	0.16
Zone-IV	G+5	1.67	0.59
	G+10	3.3	0.30
	G+15	3.4	0.30
	G+20	6.12	0.16
Zone-V	G+5	1.69	0.59
	G+10	3.3	0.30
	G+15	3.3	0.30
	G+20	6.13	0.16

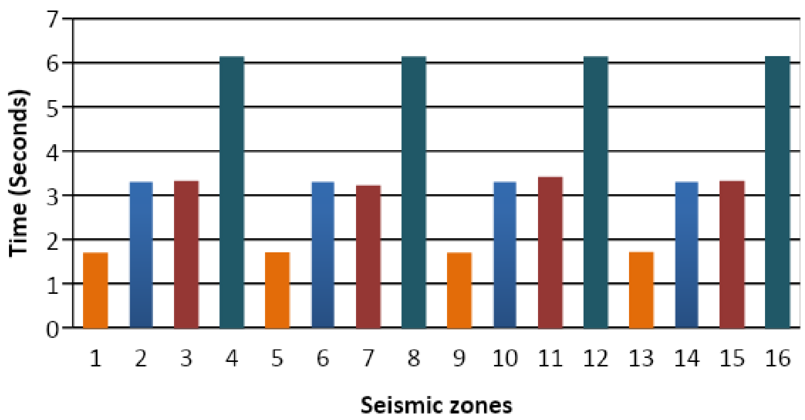


Fig. 12. Comparison of fundamental time period of different building height vs. seismic zones

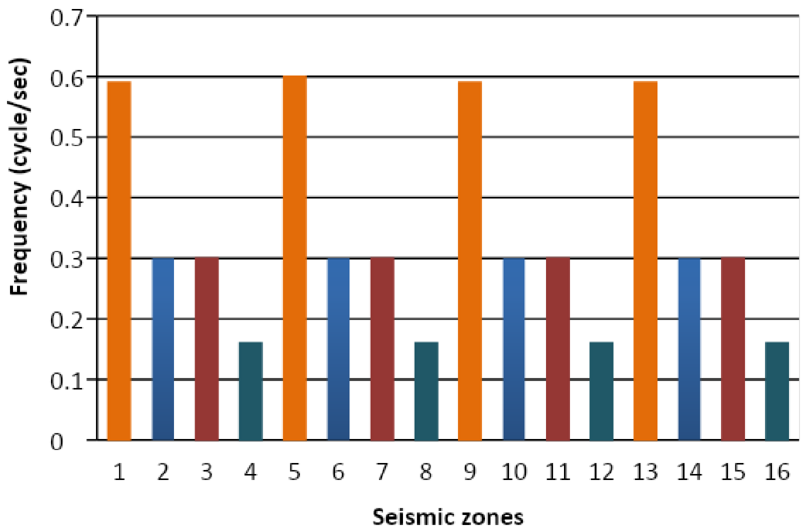


Fig. 13. Comparison of frequencies of different building height vs. seismic zones

4. Discussion

The analysis of various building heights, including G+5, G+10, G+15, and G+20 storey buildings, revealed distinct maximum storey displacements. In the X direction, the G+5 storey building exhibited a maximum displacement of 29.5mm, increasing to 51.8mm for the G+10 storey building, 78mm for the G+15 storey building, and 146mm for the G+20 storey building. In the Y direction, the corresponding values were 31.8mm, 69.3mm, 97mm, and 194mm. These results indicate that, as per the analysis, the maximum storey displacement values increase with the height of the building in response to varying seismic zones.

According to IS:1893, 2016 (part-1), the maximum allowable displacement at the top floor of buildings should not exceed 0.004h, which translates to 88mm for G+5 storey, 148mm for G+10 storey, 208mm for G+15 storey, and 268mm for G+20 storey buildings. However, the case study revealed lower displacement values: 31.8mm for G+5 storey, 69.3mm for G+10 storey, 97mm for G+15 storey, and 194mm for G+20 storey. Therefore, the analysis results indicate that the displacements are within acceptable limits compared to the maximum allowable displacement values.

The maximum base shear values for different building heights also vary with seismic zones. In the X direction, the G+5 storey building experienced a maximum base shear of 728KN, which increased to 777KN for the G+10 storey building, 978KN for the G+15 storey building, and 1015KN for the G+20 storey building. In the Y direction, the corresponding values were 728KN, 780KN, 998KN, and 1021KN. These findings suggest that the maximum base shear increases with the height of the building in response to different seismic zones.

Similarly, the maximum base moment values for different building heights vary in response to seismic zones. In the X direction, the G+5 storey building exhibited a maximum base moment of 210KN.m, which increased to 246KN.m for the G+10 storey building, 259KN.m for the G+15 storey building, and 301KN.m for the G+20 storey building. In the Y direction, the corresponding values were 210KN.m, 267KN.m, 305KN.m, and 324KN.m. The analysis indicates that, as per the results, the maximum base moments increase with the height of the building in different seismic zones.

The study also examined the maximum base shear, base moment, and displacement for a G+20 multi-storey building across global X and Y directions. The fundamental time period for different building heights was determined. For G+5 storey, it was 1.68 Sec, for G+10 storey, 3.3 Sec, for G+15 storey, 3.4 Sec, and for G+20 storey, 6.12 Sec. notably, these values remained relatively consistent across different seismic zones. Regarding the frequency of oscillation, the G+5 storey building exhibited a frequency of 0.60 cycle/sec, while the G+10 storey and G+15 storey buildings had a frequency of 0.3 cycle/sec. The G+20 storey building had a slightly lower frequency of 0.16 cycle/sec. These frequencies were comparable across various seismic zones for each building height.

Conclusion

In conclusion, the findings of this study, conducted using the response spectrum method on multi-story residential buildings of varying heights (G+5, G+10, G+15, and G+20 storeys), yield several significant insights:

1. Seismic analysis is imperative for ensuring the structural integrity of buildings. The investigation showed that, with increasing building height, the maximum storey displacement, base shear, and moment values also increase in response to varying seismic zones.
2. Notably, the largest storey displacement, base shear, and moment values were observed in G+20 storey buildings in seismic zone V, compared to zones II, III, and IV. This suggests that the structure's uniform stiffness can help mitigate displacement, base shear, and moment, enhancing overall performance.
3. The study examined the resonance effect by comparing the approximate time period (Ta) of oscillation, as per IS 1893:2016 (Part-1), with the analysis results. The results indicated that multi-storied residential buildings are safe from resonance effects.
4. Furthermore, it was observed that, for buildings of the same height, the frequency and time period values remained consistent across different seismic zones.

5. The study also revealed an inverse relationship between frequency and time period, with frequency decreasing as building height increases. This insight is crucial for understanding the behaviour of high-rise buildings.

In light of these findings, it is recommended that seismic analysis is essential for buildings above G+10 storeys to ensure their performance against seismic forces. The analysis results have provided valuable comparisons across different structure heights in low to high seismic zones in India. The methodology employed in this study offers opportunities for further research. Future investigations could compare results obtained in soft and rocky soil within different seismic zones or explore soil-structure interactions to enhance our understanding of seismic responses.

6. References

1. Indian Standard code: IS 1893-2016 (part-1), "Criteria for seismic wave-resistant design of building structures."
2. Indian Standard code: IS 456:2000, "Criteria for plain and reinforced structures," Bureau of Indian Standards.
3. IS 875: 1987, "Code of practice for seismic loads for building and structures – Part 1: Dead loads" and "Part 2: Imposed loads."
4. Dehankar, Y., & Shelke, N., "Seismic Analysis of Different Heights Building on Different Types of Soil Using Base Isolation Technique," International Journal of Innovative Research in Engineering, Volume 3, Issue 3 (May-June 2022), pp. 336-352. [Online] Available at: www.theijire.com
5. Ahamad, S. A., & Pratap, K. V., "Dynamic analysis of G + 20 multi storied building by using shear walls in various locations for different seismic zones," Journal Article. [Online] Available at: www.elsevier.com/locate/matpr
6. Danam, V., "Comparative Study on Multistoried RCC Structure with and without Shear," Publication at: https://www.researchgate.net/publication/310478569
7. Adam, F. M., "Seismic Analysis of a Reinforced Concrete Building by Response Spectrum Method," Article in IOSR Journal of Engineering, September 2013. [Online] Available at: https://www.researchgate.net/publication/281409966
8. Saatcioglu, M., & Humar, J., "Dynamic analysis of buildings for earthquake-resistant design." DOI: 10.1139/L02-108.

9. Somasundar, K. M., Leslie, R., & Xavier, B., "Study of comparison of applying modes in response diapason system." Journal of Advanced Research in Engineering & Management, Vol. 03- Issue 11-2017, pp. 43-65.
10. Chandrakar, P., & Bokare, P. S., "A Review- Comparison between RS Method and Time History Method for Dynamic Analysis." International Journal of Research, Volume 6 Issue 5, May 2017.
11. Raheem, J., Rana, D., "Seismic Analysis of Vertical & Regular RCC Framed structures."
12. Reddy, K. R., & Rao, S. V. M., "Seismic Analysis of High Raised Structure by Response Diapason System," International Journal of Advance Technology and Innovative Exploration, Vol. 08, pp. 4111-4118, 2016.
13. Kulkarni, T., et al., "Analysis and Design of High-Rise Structure Frame using Staad Pro," IJRET International Journal of Research in Engineering and Technology, Vol. 05, Issue 04, 2016.
14. Khandve, A. V., et al., "Seismic Response of RC Frame Structures with Soft Storeys," International Journal of Engineering Research, Vol. 2, Issue 3, pp. 2100-2108, 2012.
15. Deshmukh, S. M., & Kulkarni, J. G., "Analysis of Incompletely Braced Multistorey Building Frames due to Graveness and Earthquake Loads," International Journal of Advance Research In Science and Engineering, Vol. 2, Issue No. 8, 2013, ISSN 2319-8354.
16. Kadid, A., & Boumrkik, A., "Pushover Analysis of Reinforced Concrete Frames Structures," Asian Journal of Civil Engineering (Building and Housing), VOL. 9, No. 1, 2008, pp. 75-83.

Chapter-8:

Leveraging Open Innovation for Sustainable R&D: Collaborative Approaches to Global Environmental Challenges

Diganta Bhattacharyya

Swami Vivekananda University, Kolkata, Pin-700121, West Bengal India.

** Communicating author's email: digantab@svu.ac.in*

Leveraging Open Innovation for Sustainable R&D: Collaborative Approaches to Global Environmental Challenges

Diganta Bhattacharyya

Swami Vivekananda University, Kolkata, Pin-700121, West Bengal India.

** Communicating author's email: digantab@svu.ac.in*

Abstract:

The increasing severity of global environmental challenges, such as climate change, resource depletion, and pollution, demands innovative approaches to research and development (R&D). Open innovation, characterized by collaborative partnerships across industries, governments, and academia, presents a potential solution to promote sustainable practices in R&D. This paper explores the role of open innovation in sustainable R&D by examining collaborative approaches aimed at addressing environmental challenges. It outlines best practices, success stories, and policy recommendations to foster greater integration of open innovation into global sustainability efforts.

Keywords:

Open Innovation, Sustainable R&D, Global Environmental Challenges, Collaborative Approaches, Green Innovation, Circular Economy, Climate Change, Public-Private Partnerships.

1. Introduction

Global environmental challenges, such as climate change, biodiversity loss, and resource scarcity, present urgent problems that demand innovative and collaborative solutions. Traditional R&D methods, often siloed within specific industries or institutions, are insufficient to address the scope and complexity of these issues. Open innovation offers an alternative framework where the exchange of ideas, knowledge, and technology across organizational boundaries promotes more effective and sustainable R&D outcomes. This paper investigates how open innovation models are being leveraged for sustainable development and offers insights into collaborative strategies to tackle global environmental challenges.

2. Open Innovation in R&D

Open innovation, first popularized by Chesbrough (2003) [1], involves sharing knowledge, resources, and technologies across organizational boundaries to accelerate innovation. In the context of sustainable R&D, open innovation enables diverse stakeholders, such as companies, governments, academic institutions, and non-profits, to pool resources and expertise to develop environmentally sustainable solutions.

3. The Role of Open Innovation in Addressing Environmental Challenges

Open innovation has gained traction in addressing global environmental challenges by enabling multi-stakeholder collaboration and resource sharing. By working together, stakeholders from various sectors can create more comprehensive solutions that consider the environmental, economic, and social dimensions of sustainability. For example, the European Union’s Horizon 2020 program has used open innovation frameworks to address climate action and resource efficiency [2]. Similarly, corporate initiatives like the World Business Council for Sustainable Development (WBCSD) encourage cross-industry collaboration for green innovation [3].

4. Collaborative Approaches to Sustainable R&D

4.1 Public-Private Partnerships (PPPs)

Public-private partnerships (PPPs) are vital components of open innovation models, particularly in sustainable R&D. Governments and private companies collaborate to share knowledge, de-risk investments, and promote the commercialization of sustainable technologies. For example, in the renewable energy sector, collaborations between governments and energy companies have accelerated the development of solar, wind, and bioenergy technologies [4]. The success of PPPs lies in their ability to align public interests with private-sector innovation capabilities.

4.2 Industry-Academia Collaboration

Collaborations between industry and academia are instrumental in leveraging scientific research for practical applications in sustainability. Academic institutions provide foundational research, while industries contribute practical expertise and commercialization pathways. Projects like the Circular Economy Innovation Network exemplify how academia and industry can co-develop sustainable business models, focusing on resource reuse and waste minimization [5].

4.3 Crowdsourcing and Citizen Science

Crowdsourcing and citizen science initiatives have also emerged as open innovation strategies that mobilize the general public in environmental problem-solving. Platforms such as Zooniverse and the European Space Agency's Climate from Space program engage citizen scientists to collect and analyze environmental data, contributing to research on biodiversity, pollution, and climate change [6]. These initiatives increase the accessibility of scientific research and foster wider participation in sustainability efforts.

5. Case Studies of Successful Open Innovation Models in Sustainability

5.1 The Ellen MacArthur Foundation and Circular Economy

The Ellen MacArthur Foundation is a prominent example of an organization using open innovation to advance the circular economy, a system aimed at minimizing waste and maximizing resource efficiency. Through collaboration with multinational companies, governments, and academia, the Foundation has accelerated the adoption of circular business models across various sectors, including plastics, textiles, and electronics [7].

5.2 The Global Open Data for Agriculture and Nutrition (GODAN) Initiative

GODAN is another example of open innovation for sustainability. This initiative focuses on making agricultural and nutrition data accessible to researchers, policymakers, and farmers. By facilitating data sharing, GODAN promotes sustainable agricultural practices and food security in regions vulnerable to climate change impacts [8].

6. Challenges and Barriers to Open Innovation in Sustainable R&D

Despite the promise of open innovation, several challenges remain. Intellectual property (IP) concerns often deter companies from sharing proprietary information, while cultural and organizational differences can impede collaboration between diverse stakeholders [9]. Furthermore, disparities in funding and resources between organizations can limit participation in open innovation initiatives, particularly for smaller enterprises and developing countries. Overcoming these challenges requires the development of robust policy frameworks that support IP sharing, equitable participation, and adequate financing mechanisms for open innovation in sustainable R&D.

7. Policy Recommendations for Enhancing Open Innovation in Sustainability

To foster greater adoption of open innovation in sustainable R&D, governments and international organizations must take a proactive role in establishing supportive policies. Key recommendations include:

- **Incentivizing Collaboration:** Governments should offer financial incentives, such as tax breaks or grants, to encourage companies and academic institutions to participate in open innovation initiatives.
- **Creating Shared IP Frameworks:** Developing standardized IP-sharing agreements can help alleviate concerns about proprietary knowledge while fostering collaboration.
- **Facilitating Access to Data:** Expanding open data platforms that enable access to environmental and sustainability data can enhance the quality and reach of open innovation efforts.

8. Conclusion

Open innovation presents a powerful tool for advancing sustainable R&D and addressing global environmental challenges. By fostering collaboration across sectors, industries, and disciplines, open innovation enables the development of more holistic, scalable, and impactful solutions. Governments, businesses, and research institutions must work together to overcome the barriers to open innovation and build frameworks that encourage its integration into global sustainability efforts.

References

1. Chesbrough, H. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Harvard Business School Press.
2. European Commission. (2020). *Horizon 2020 Climate Action, Environment, Resource Efficiency and Raw Materials*.
3. World Business Council for Sustainable Development (WBCSD). (2021). *Green Innovation Projects*.

4. IEA (2021). *Public-Private Partnerships for Clean Energy Deployment*. International Energy Agency.

5. Circular Economy Innovation Network. (2022). *Industry-Academia Collaboration for Sustainable Business Models*.

6. Zooniverse. (2023). *Citizen Science Projects*.

7. Ellen MacArthur Foundation. (2020). *Circular Economy and Open Innovation*.

8. GODAN (2022). *Global Open Data for Agriculture and Nutrition Initiative*.

9. Hagedoorn, J., & Zobel, A. (2015). The Role of Intellectual Property Rights in Open Innovation. *Research Policy*, 44(3), 1042-1053.

Chapter-9:

Impact of media awareness in curtailing of Typhoid fever contagion

Piu Samui[1,*], Jayanta Mondal[2]

[1]Department of Mathematics, Swami Vivekananda University, Barrackpore, West Bengal-700121, India

[2]Department of Mathematics, Diamond Harbour Women's University, Sarisha, West Bengal-743368, India

*Corresponding Author Email: *pius@svu.ac.in*

Impact of media awareness in curtailing of Typhoid fever contagion

Piu Samui[1,*], Jayanta Mondal[2]

[1]Department of Mathematics, Swami Vivekananda University, Barrackpore, West Bengal-700121, India

[2]Department of Mathematics, Diamond Harbour Women's University, Sarisha, West Bengal-743368, India

*Corresponding Author Email: *pius@svu.ac.in*

Abstract

Typhoid fever, declared as one of the life - threatening contagion by World Health Organization (WHO), is brought about by Salmonella Typhi bacterium. Typhoid fever is transmitted by contaminated sanitation, filthy drinking water, poor hygiene (especially during food taking) and treatment of Typhoid fever is enormously complicated and costly due to antimicrobial resistance. In this study, we present a four dimensional mathematical model portraying the transmission dynamics of Typhoid fever incorporating the impact of media awareness (via Radio, TV, newspapers, social media, awareness campaigns etc) in incidence, propagation and prevention of the infection. Feasible steady states of the epidemic system are determined and the basic reproduction of the system is investigated through next-generation matrix method. Local stability of the system around the steady states are analyzed in regard to basic reproduction number. Numerical simulations are carried out in order to verify overall analytical outcomes.

Keywords: Typhoid fever; media awareness; basic reproduction number; stability

Introduction

Typhoid fever, a fatal human infectious disease caused by the Salmonella enterica serotype Typhi bacteria that is also termed as Salmonella Typhi is a type of enteric fever found only in humans. According to the National Center for Disease Control (NCDC), In India, typhoid has been the most prevalent water-borne disease between 2022 and 2024, affecting about 4.5 million people annually and resulting in around 9,000 deaths [*https://ncdc.mohfw.gov.in/*].

According to the centers for Disease Control and Prevention (CDC) report, approximately 11–21 million cases of typhoid fever documented globally per year, causing about 135,000 – 230,000 deaths cases [*https://www.cdc.gov/typhoid-fever/about/index.html*]. According to the World Health Organization, expansion in urbanization, climate changes, increased resistance rate of antibiotic treatment is enhancing the global burden of typhoid fever [https://www.who.int/news-room/fact-sheets/detail/ *typhoid*]. Although vaccination against typhoid fever is available from six months up 65 years, drug resistance is causing complications in proper antibacterial treatment. Plausible prevention measures of typhoid fever are antibiotics, vaccine, safe and proper practice of hygiene,

***Corresponding Author: Email: pius@svu.ac.in**

safe sanitation, proper and safe practice of food and water taking etc.

Media awareness is very helpful to acknowledge people about the prevalence of a highly communicable disease, course of the infection, preventive measure, and to promote vaccination uptake. Public health departments follow various paths like TV, Radio, internet, newspapers, You Tube and social media to aware people regarding the outbreak of an infection and its possible control. In our present study, we incorporate the impact of media awareness in our proposed model. Epidemiological models have great assistance in describing the overall intricate dynamics of infectious diseases and to trace different epidemiological factors. A handful of mathematical models describing the transmission dynamics of typhoid fever have been conducted by various researchers worldwide [Adetunde2008, Edward2016, Edward2017, Funk2009, Khan2015, Liu 2008, Mondal2022, Mushayabasa2012, Mushayabasa2014, Rai2019]. Motivated from these researches, we propose a deterministic model depicting the typhoid fever dynamics in human populations.

The article is synchronized as follows: in the very next Section, we formulate our proposed mathematical model of typhoid fever transmission. In Section 3, basic characteristics of the epidemic system such as positivity and uniform boundedness are studied. The equilibrium points of the epidemic system are analyzed along with their existence criteria and the basic reproduction number of the system is computed in Section 4. In Section 5, the local asymptotic stability of the epidemic system around the endemic steady state is investigated. In Section 6, some numerical simulations are presented and analytical results are validated numerically. Conclusions regarding overall model analysis is attached.

The mathematical model

We have constructed a deterministic, four dimensional ODE model considering susceptible St - the number of individuals who can be infected but have not yet contracted the Salmonella typhi but may contract it if exposed to any mode of its transmission; infectives It - the number of individuals who have contracted the Salmonella typhi and are actively or capable of transmitting it; recovered Rt - the number of individuals who are recovered after treatment or media awareness programs and are immune to disease and Mt - the cumulative density of awareness programs driven by media. Our proposed model assumes that, due to awareness programs, uninfected population form a different class and they are sufficiently aware to avoid contacting with the infected population.

$$dSdt = \lambda\text{-}\alpha SI\text{-}1bSM+\omega R\text{-}\mu S,\ dIdt = \alpha SI\text{-}\delta I\text{-}\gamma I\text{-}\mu I,\ dRdt = \gamma I+1bSM\text{-}\omega R\text{-}\mu R,\ dMdt = 0I\text{-}\theta M, \quad (1)$$

with epidemiologically feasible initial conditions

$$St0>0,It0\geq 0,Rt0\geq 0,Mt0\geq 0. \quad (2)$$

Here, t=t0denotes the initial day of infection where λ is the recruitment rate of individuals into the community by birth or migration (Susceptible), the per capita mortality rate of susceptible, Infected and Recovery are denoting . The typhoid fever-indicated mortality rate. The rate of infection is a, b be the dissemination rate of awareness programs between aware individual and uninfected population. Here 1 is the proportionality constant which governs the implementation. The constant recovery rate and disease-induced death rate of infected individuals and respectively. The constant denote the rate of recovery of aware susceptible due to social factor. The proportionality constant 0 be the rate at which the awareness campaigns by media and represents the depletion rate of these programs due to ineffectiveness.

Positivity and boundedness of solution

In this section we provided to prove the positivity and boundedness of the system *(1)* with initial condition S0,I0,R0,M0TR+4. We first state the following lemma.

Lemma 1. *Suppose* Ψ⊂R×C *is open,* fi∈CΨ,R, *i=1, 2,3, ..., n. If* fi|xit=0,XtC+0n ≥0, Xt=x1t,x2t,...,xntT, *then* C+0n{ψ=1,2,...,n:ψ∈C-τ,0,R+0n} *is the invariant domain of the following equations.* dxitdt=fit,Xt,t≥κ,i=1,2,3,...,n, *where* R+0n={x1,x2,...,xn*:* $x_{i \geq 0}$, *i= 1, 2, . . ., n}*

Proposition 1. *The system* (1) *is invariant in* R+4.

Proof. Re-writing the system *(1)*, we have

$$dXtdt=BXt,X0=X0\geq 0,$$

BXt=B1Xt,B2Xt,B3Xt,B4XtT. It is noted that

$$dSdt|S=0 = \lambda+\omega R>0,dIdt|I=0=\alpha SI>0,\ dRdt|R=0 = \gamma I+1bSM>0,dMdt|M=0=0I>0.$$

Thus, it is followed from the Lemma 1 that R+4 is an invariant set.

Lemma 2. *The system* (1) *is uniformly bounded , where feasible regions is defined by* = {(S, I, R) ∈ (R0+)3 | S+ I + R ≤ : M∈ R0+ | M ≤ λ 0μ θ}

with the non-negative initial conditions S0>0,I0≥0,R0≥0 *and* M0≥0*.*

Proof. Firstly, let us choose a time dependent function: H1=S+I+R and clearly it is seen that

$$dH1dt=dSdt+dIdt+dRdt.$$

From the system equations *(1)*, we have

$$dH1dt =\lambda-\delta I-S+I+R\mu, \quad \leq\lambda-\mu\ H1.$$

where is considered as the minimum of {μ+δ,μ}. Thus, it is seen that

$$dH1dt+\mu H1\leq\lambda.$$

Applying the theorem of differential inequality [Rota1987], we obtain

$$0<H1tH10e-\mu t+.$$

Now, taking limit as t→∞, we have,

$$0<H1.$$

Again, from the last equation of the system *(1)*, we get

$$dMdt = 0I-\theta M, \qquad \lambda\ 0\mu\ -\ \theta M$$

With the help of the theorem of differential inequality [Rota1987], we obtain

$$0<M\leq M0e\text{-}0t+0\mu\theta.$$

Thus, taking $t\rightarrow\infty$, we have

$$0<M\leq 0\mu\theta.$$

Consequently, all the solutions of the system *(1)* along with non-negative initial conditions are uniformly bounded in the region .

Steady States

In this Section, the feasible equilibrium executed by the epidemic system *(1)* and their existence criteria would be studied.

Disease-free equilibrium (DFE)

The epidemic system *(1)* possesses a DFE, say, $E0\lambda/\mu,0,0,0$ and it always exists, without any epidemic condition. In this equilibrium, the whole population is free from the infection and hence there is no media awareness as well.

Now, we compute the basic reproduction number (R_0) (say) of the epidemic system *(1)* determining the average number of secondary infections using the next-generation matrix method proposed by Driessche and Watmough [Van den Driessche. 2002]. The basic reproduction number R_0 for the epidemic system *(1)* is computed as follows:

$R0=\lambda\alpha\mu+\delta+\gamma.$

Endemic equilibrium (EE)

The epidemic system (1) exhibits an endemic equilibrium (EE) $E^*S^*,I^*,R^*,M^*$where the components of EE (E^*) are computed as

$$S^* = \delta+\mu+\gamma,\ I^* = \omega+\mu1\text{-}1R0\omega+\mu\delta+\mu+\gamma\alpha+1b0\text{-}\omega\alpha\gamma\theta+1b0\delta+\mu+\gamma,\ R^* = \omega+\mu\gamma\theta+1b0\delta+\mu+\gamma1\text{-}1R0\omega+\mu\delta+\mu+\gamma\alpha+1b0\text{-}\omega\alpha\gamma\theta+1b0\delta+\mu+\gamma,\ M^* = 0\omega+\mu1\text{-}1R0\omega+\mu\delta+\mu+\gamma\alpha+1b0\text{-}\omega\alpha\gamma\theta+1b0\delta+\mu+\gamma.$$

Since all the model parameters are positive, we would get positive values of the components S^*, I^*, R^* and M^* only if $R0>1$ and

$$\omega+\mu\delta+\mu+\gamma>\omega\theta\gamma+\omega1b0\delta+\mu+\gamma.$$

Remark 1: It is observed from the expression of I* that dI*db<0 and dI*d0<0. This is indicating the fact that cumulative number of infective individuals is decreasing with an increase in the value of the dissemination rate of awareness and the implementation rate of awareness programs.

Local stability analysis

In this section, we investigate the local asymptotic stability of the epidemic system *(1)* around the endemic steady state (E*). In this aspect, we first compute the Jacobian matrix of the epidemic system *(1)* around E* as

$$J^*=-I^*+1bM^*+\mu\ -\alpha S^*\ \ -1bS^*\ I^*\ 0\ 0\ 0\ 1bM^*\ \ -\omega+\mu\ a3\ 0\ 0\ 0\ -\theta\ .$$

Let us define $a1=\alpha I^*+1bM^*+\mu$, $a2=\alpha S^*$, $a3=1bS^*$, $a4=\alpha I^*$, $a5=1bM^*$ and $a6=\omega+\mu$. now, the characteristic equation of the Jacobian matrix E* is computed as

$$4+A13+A22+A3\vartheta+A4=0,$$

where,

$$A1 = a1+a6+\theta, A2=a1a6+\theta+a6\theta+a2a4-a5,\ A3 = a1a6\theta+a2a4a6+\theta+a2a40-\omega\gamma a4-\theta a5,\ A4 = a2a4a6+a3a4a60-\omega\theta\gamma a4-\omega 0a3a4.$$

Now, according to the well-known Routh-Hurwitz criterion, it is followed that the epidemic system *(1)* around the endemic equilibrium E* is locally asymptotic stable if

$$A1>0, A4>0, A1A2-A3>0 \ \text{ and } \ A1A2A3-A32-A4A1>0.$$

The result can be summarized in the following theorem:

Theorem 1. *The endemic equilibrium* E* *is stable only if* R0>1 *and*

$$0b<\min\mu+\delta+\gamma 1,\omega\gamma\mu+\delta+\gamma$$

follows; otherwise, the system would be unstable.

Remark 2: From the above inequality, it is seen that for the inevitable satisfaction of the conditions b=0 and 0=0, it is implied that due to awareness programs and by quarantining some susceptible from infectives, the typhoid fever infection could be controlled.

Numerical simulations

In this Section, we numerically validate our proposed epidemic model *(1)* with the baseline parameter values taken as λ=1000,α=0.012,δ=0.01,ω=0.5,1=0.1,γ=0.01,μ=0.8,b=0.04,θ=0.01,1=0.01 and using the Matlab software. With the help of these baseline parameter values, it is seen that the value of the basic reproduction number (R0) is 1.2069 > 1. In Figure 1 and Figure 2 , the local asymptotic stability of the epidemic system (1) around the disease-free equilibrium point (E0) and the endemic equilibrium point (E*) are portrayed respectively. The figures also indicate that media awareness is necessary to decrease the level of infection.

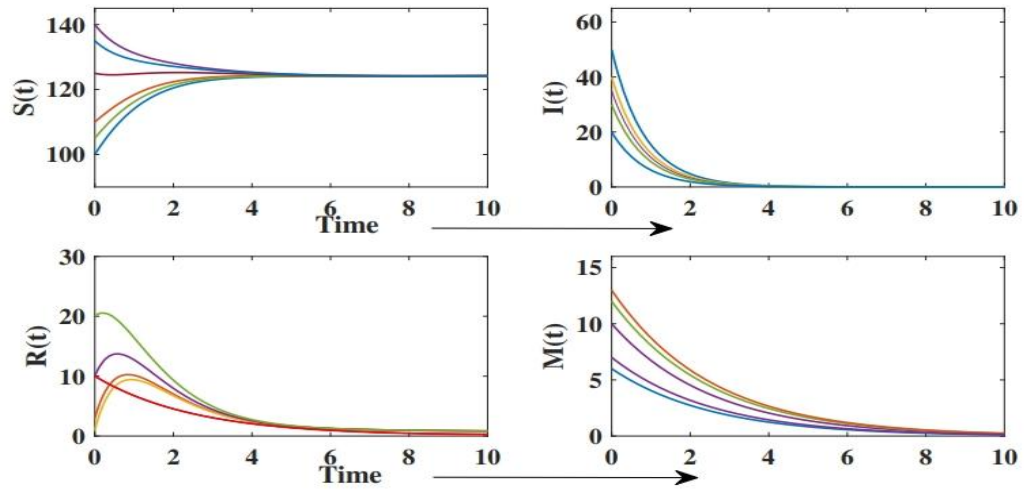


Figure 1: The figure shows that the time series evolution for $R_0 = 0.5213 < 1$ indicating the locally asymptotically stability of the epidemic system around the disease-free equilibrium point, $E_0(128, 0, 0, 0)$.

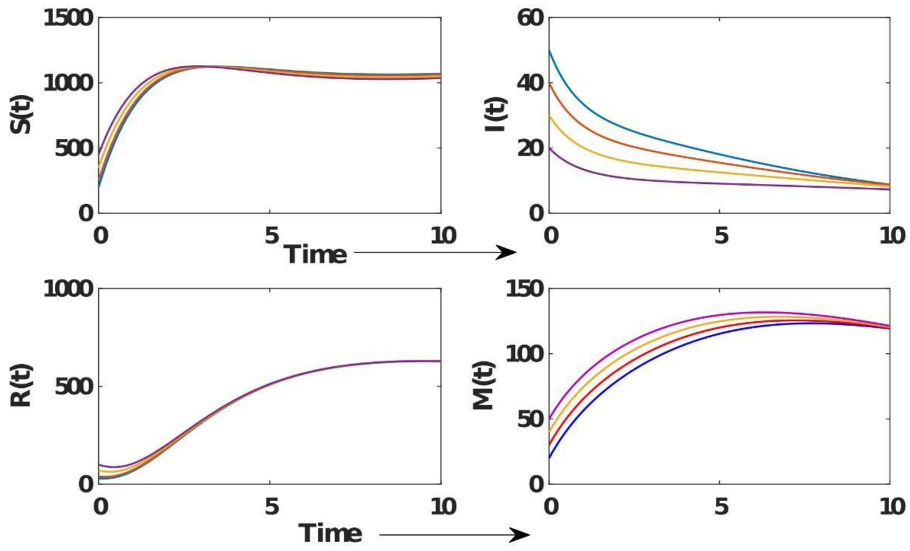


Figure 2: The figure shows that the time series evolution for R_0 = 1.2069 > 1 indicating the locally asymptotically stability of the epidemic system around the endemic equilibrium point, E^*.

Discussion and Conclusions

In this present article, a four dimensional ODE deterministic model is presented to capture the role of media awareness in mitigating the global burden of typhoid fever transmission. The model is analysed both analytically and numerically. The system has one disease-free equilibrium point and one endemic equilibrium point. The local asymptotic stability of the epidemic system around the steady states are investigated suggesting the fact that media awareness is necessary in reducing the global burden of typhoid fever transmission.

References:

1. National Center for Disease Control: Weekly Outbreak Report. https://ncdc.mohfw.gov.in/ . Retrieved in August, 2024.
2. Centers for Disease Control and Prevention: About Typhoid Fever and Paratyphoid Fever. https://www.cdc.gov/typhoid-fever/about/index.html . Retrieved in April 25, 2024.
3. World Health Organization: Typhoid. https://www.who.int/news-room/fact-sheets/detail/ *typhoid*. Retrieved in March 30, 2023.
4. Adetunde, I. A., 2008. Mathematical models for the dynamics of typhoid fever in kassena-nankana district of upper east region of Ghana. *J. Mod. Math. Stat*, *2*(2), 45-49.
5. Edward, S., & Nyerere, N., 2016. Modelling typhoid fever with education, vaccination and treatment. *Eng. Math*, *1*(1), 44-52.
6. Edward, S., 2017. Modelling and stability analysis of Typhoid fever transmission dynamics with control strategies. *International Journal of Sciences: Basic and Applied Research*, *32*(1), 151-168.

7. Funk, S., Gilad, E., Watkins, C., & Jansen, V. A., 2009. The spread of awareness and its impact on epidemic outbreaks. *Proceedings of the National Academy of Sciences*, *106*(16), 6872-6877.

8. G. Birkhoff, and G. Rota, 1987. Ordinary Differential Equations. Wiley, New York.

9. Khan, M. A., Parvez, M., Islam, S., Khan, I., Shafie, S., & Gul, T., 2015. Mathematical analysis of typhoid model with saturated incidence rate. *Advanced Studies in Biology*, *7*(2), 65-78.

10. Liu, Y., & Cui, J. A. , 2008. The impact of media coverage on the dynamics of infectious disease. *International Journal of Biomathematics*, *1*(01), 65-74.

11. Mondal, J., Khajanchi, S., & Samui, P., 2022. Impact of media awareness in mitigating the spread of an infectious disease with application to optimal control. *The European Physical Journal Plus*, *137*(8), 983.

12. Mushayabasa, S., 2012. A simple epidemiological model for typhoid with saturated incidence rate and treatment effect. *International Journal of Mathematical and Computational Sciences*, *6*(6), 688-695.

13. Mushayabasa, S., 2014. Modeling the impact of optimal screening on typhoid dynamics. *International Journal of Dynamics and Control*, *4*, 330-338.

14. Van den Driessche, P., & Watmough, J., 2002. Reproduction numbers and sub-threshold endemic equilibria for compartmental models of disease transmission. *Mathematical biosciences*, *180*(1-2), 29-48.

Chapter-10:

Sustainable R&D in the Era of Digital Transformation: Opportunities and Challenges

Sourav Saha[1,*]

[1,*]*Swami Vivekananda University, Kolkata, Pin-700121, West Bengal India.*

** Communicating author's email:* sourav@svu.ac.in

Sustainable R&D in the Era of Digital Transformation: Opportunities and Challenges

Sourav Saha[1,*]

[1,*]*Swami Vivekananda University, Kolkata, Pin-700121, West Bengal India.*

* *Communicating author's email:* sourav@svu.ac.in

Abstract

In the current age of digital transformation, research and development (R&D) is at a crossroads. The adoption of digital technologies such as Artificial Intelligence (AI), Machine Learning (ML), Internet of Things (IoT), and cloud computing has paved new pathways for sustainable R&D. However, this transition also brings numerous challenges such as data privacy, ethical concerns, and the need for new skills. This paper examines the opportunities and challenges that organizations face while integrating sustainability with digital R&D and explores strategies for leveraging these technologies for a sustainable future.

Keywords: Sustainable R&D, Digital Transformation, Artificial Intelligence, Machine Learning, IoT, Sustainability, Data Privacy, Ethical Challenges

1. Introduction

Digital transformation has become a catalyst for reshaping various sectors, including research and development (R&D). As organizations embrace technologies like AI, IoT, blockchain, and cloud computing, they simultaneously face new challenges in making these R&D activities sustainable. Sustainability in R&D refers not only to environmental responsibility but also to maintaining ethical, economic, and social dimensions over the long term. However, this transition requires a balance between innovation and responsible technology adoption.

This paper will discuss the multifaceted opportunities that arise from digital transformation in R&D and the inherent challenges that need to be addressed. These include ethical issues, data security, talent acquisition, and resource allocation. It will also propose a set of best practices to help organizations pursue sustainable R&D.

2. Opportunities in Sustainable R&D During Digital Transformation

2.1 Enhanced Efficiency and Innovation through Digital Tools

The integration of digital technologies such as AI and machine learning into R&D processes allows for faster experimentation, simulation, and analysis. AI, for example, can accelerate drug discovery by analysing vast amounts of data in real-time, reducing the need for extensive physical testing[1]. Furthermore, digital twins and predictive analytics enable organizations to model and optimize operations before committing resources, reducing waste and increasing efficiency [2].

2.2 Sustainability through IoT and Automation

IoT devices enable real-time monitoring of systems and processes, which leads to better resource management. In sustainable R&D, IoT can optimize energy consumption and reduce emissions through smarter systems. Moreover, automation reduces the amount of manual labor needed, leading to more efficient production processes that consume fewer resources and produce less waste [3].

2.3 Open Innovation and Global Collaboration

Digital platforms have made it easier for companies to collaborate globally and share innovations. Open-source platforms and cloud-based solutions enable researchers from different parts of the world to work together in real time. This collaborative approach enhances knowledge-sharing and contributes to sustainable innovation by avoiding duplication of efforts [4].

2.4 Incorporation of Green Technologies

Emerging green technologies, like renewable energy systems, are increasingly integrated into the R&D ecosystem. The use of digital technologies can facilitate the design and implementation of greener production methods. For instance, AI and big data analytics can help companies identify areas where energy consumption can be minimized, further promoting sustainability [5].

3. Challenges in Achieving Sustainable R&D

3.1 Data Privacy and Security

One of the primary concerns in digital R&D is data privacy and cybersecurity. With increased digital transformation, sensitive research data becomes vulnerable to cyberattacks. Protecting intellectual property and ensuring the security of sensitive information remains a top priority for organizations. [6]

3.2 Ethical and Regulatory Challenges

Ethical concerns arise as AI and automation play a larger role in R&D. Issues such as bias in AI algorithms, ethical use of personal data, and the implications of replacing human labor with machines must be carefully considered. Regulatory frameworks also struggle to keep pace with technological advancements, leading to potential risks in compliance [7].

3.3 Skill Gaps in the Workforce

The digital transformation of R&D demands a highly skilled workforce proficient in data science, AI, and other emerging technologies. However, many organizations face a significant skills gap, with the current workforce lacking the necessary expertise to implement and manage these technologies effectively [8]. Training and development programs must be prioritized to bridge this gap.

3.4 Resource Allocation and Environmental Impact

Sustainability efforts can sometimes conflict with the resource-intensive nature of digital technologies. High energy consumption in data centres, e-waste from obsolete hardware, and the environmental costs of large-scale computing infrastructure present significant challenges to sustainability goals [8]. Careful planning and investment in green IT solutions are essential to mitigate these impacts.

4. Best Practices for Sustainable R&D in the Digital Age

4.1 Adopting Green IT Solutions

Organizations should invest in energy-efficient data centres, renewable energy sources, and environmentally friendly hardware to reduce their carbon footprint. Sustainable R&D requires integrating digital transformation strategies with eco-friendly technologies [10].

4.2 Building a Culture of Ethical Innovation

To ensure that R&D activities remain sustainable, businesses should focus on creating a culture of ethical innovation. This involves adhering to regulatory frameworks, prioritizing transparency, and actively involving stakeholders in decision-making processes [11].

4.3 Continuous Skill Development

Organizations must address the skills gap by providing ongoing training in digital tools, data analytics, and AI. Collaborative programs between industry and academia can help create a workforce ready to meet the challenges of digital transformation [12].

4.4 Leveraging Digital Twins and Simulation

Using digital twins to simulate processes before full-scale deployment can save resources and minimize environmental impact. Simulations can identify inefficiencies and help R&D teams design more sustainable solutions. [13].

Conclusion

Digital transformation offers vast opportunities for enhancing the efficiency, innovation, and sustainability of R&D. However, achieving sustainable R&D in this era requires organizations to address key challenges, including data security, ethical considerations, and workforce development. By adopting best practices like investing in green IT, fostering a culture of ethical innovation, and emphasizing continuous learning, companies can align their R&D efforts with sustainability goals. The future of sustainable R&D will depend on how well organizations navigate the complexities of digital transformation while keeping environmental, ethical, and social responsibilities at the forefront.

References

1. Smith, J. & Wilson, K. (2020). Accelerating Drug Discovery through AI: A Review of Techniques and Applications. *Journal of Computational Biology*, 27(4), 233-247.

2. Green, T. (2019). The Role of Digital Twins in Sustainable Manufacturing. *Journal of Sustainable Engineering*, 14(2), 145-160.
3. Kim, S., & Lee, M. (2021). Optimizing IoT in Smart Factories: A Pathway to Energy Efficiency. *Industrial Systems Review*, 32(3), 310-322.
4. Johnson, R. & Cooper, H. (2022). Open Innovation in the Digital Age: Opportunities for Global Collaboration. *International Journal of R&D Studies*, 29(1), 65-80.
5. Patel, D., & Sharma, P. (2021). Leveraging AI for Green Energy Solutions. *Energy and AI*, 2(5), 102-115.
6. Harris, B. & Liu, T. (2020). Data Privacy and Cybersecurity in Digital R&D: Balancing Innovation and Protection. *Cybersecurity Journal*, 18(3), 211-225.
7. McNeil, G. (2022). Ethics in AI-driven R&D: Challenges and Considerations. *Ethical AI*, 5(4), 50-66.
8. Yamada, S., & Green, R. (2020). The Digital Skills Gap: Challenges for R&D in the AI Era. *Research & Development Management*, 19(2), 117-135.
9. Allen, J., & Smith, R. (2021). Environmental Impact of Digital Technologies in R&D: An Overview. *Sustainability in Technology*, 14(1), 75-90.
10. Kapoor, M. (2020). Green IT Solutions for Sustainable R&D: A Strategic Approach. *Journal of Green Computing*, 8(3), 203-220.
11. Norris, D. (2021). Building Ethical Frameworks in Digital R&D. *Innovation Ethics*, 12(2), 93-109.
12. Brown, A., & Collins, J. (2022). Bridging the Digital Skills Gap: Industry-Academia Collaborations. *R&D Futures*, 33(4), 299-315.
13. Rogers, E. (2020). The Rise of Digital Twins: Applications and Sustainability Implications. *Tech & Sustainability*, 25(3), 158-175.

Chapter-11:

Dynamic Key Management Using Blockchain for Secure Communication in Distributed Systems

Subhadip Das [1], Sarasij Majee [2], Dipanwita Maity [3]

[1]Department of Computer Science and Engineering, Swami Vivekananda University, Barrackpore, Rd Bara Kanthalia, West Bengal - 700121.

[2]Department of Computer Science and Engineering, Kalyani Government Engineering College, Kalyani, Nadia, West Bengal - 741235.

[3]Department of Pharmaceutical Technology, Maulana Abul Kalam Azad University of Technology, Haringhata, Nadia, West Bengal-741249

Dynamic Key Management Using Blockchain for Secure Communication in Distributed Systems

Subhadip Das [1], Sarasij Majee [2], Dipanwita Maity [3]

[1]Department of Computer Science and Engineering, Swami Vivekananda University, Barrackpore, Rd Bara Kanthalia, West Bengal - 700121.

[2]Department of Computer Science and Engineering, Kalyani Government Engineering College, Kalyani, Nadia, West Bengal - 741235.

[3]Department of Pharmaceutical Technology, Maulana Abul Kalam Azad University of Technology, Haringhata, Nadia, West Bengal-741249

Abstract

This work is about Blockchain-Based Dynamic Key Management for Heterogeneous Intelligent Transportation Systems.The integration of diverse technologies is changing intelligent transportation systems (ITS), necessitating the use of strong security measures to safeguard private information and communication channels.This work proposes a novel approach to key management, utilizing blockchain technology for dynamic and secure key exchange. In order to improve road safety and traffic efficiency,ITS integrates information technology into transportation infrastructures; yet, security in vehicular communication systems (VCS) is still a major concern. Secured group broadcasts can address this concern, making secure key management schemes essential for network security.In order to maintain keys securely in heterogeneous networks, this project presents a framework.Road Side Units (RSUs) are essential because they record vehicle departure information, encapsulate blocks to transfer keys, and perform rekeying inside the same security domain. To ease distributed key management in heterogeneous VCS domains,decentralized blockchain-based network topology is incorporated into the suggested system.The blockchain-based dynamic key management system aims to improve the security and efficiency of cryptographic key distribution, facilitating seamless and secure communication among the diverse components of the ITS ecosystem. Simulation and analysis demonstrate that this system provides key distribution efficiency, resilience to attacks, and adaptability to dynamic changes within the ITS ecosystem.

Keywords- distributed systems, tamper-proof, blockchain, key management, decentralization, and security.

Introduction

Dynamic key management for secure communication in distributed systems, which incorporates blockchain technology, is a viable way to address the growing security issues that contemporary networks provide. Secure, effective, and scalable key management procedures are necessary for distributed systems, especially in industries like Intelligent Transportation Systems (ITS), in order to protect the confidentiality and integrity of communications between several stakeholders. Conventional centralized key management techniques often lead to weaknesses including inefficiency in managing several communication protocols and single points of failure. Blockchain, with its decentralized, immutable, and transparent nature, overcomes these difficulties by allowing safe and transparent key transfers without the need for a central authority. Blockchain-based dynamic key management enhances the scalability and flexibility needed for diverse settings by enabling real-time changes and safe key redistribution. Additionally, by providing verifiable transaction records, the decentralized architecture promotes confidence and accountability while lowering the risks associated with harmful activity. Organizations may guarantee enhanced security, cost-effectiveness, and interoperability by integrating blockchain with distributed systems, opening the door for more robust and dependable communication infrastructures across a range of industries, including ITS, smart grids, and IoT networks.

Literature Review

For secure communication in distributed systems, dynamic key management is essential, particularly when tackling the security, scalability, and heterogeneity issues in contemporary network settings. Conventional key management techniques often suffer from centralization, inefficiency, and single point of failure susceptibility. Blockchain provides a strong answer to these issues because of its decentralized and unchangeable structure. Dynamic key management systems may guarantee safe key distribution and updates without depending on a centralized authority by using blockchain. The immutability of blockchain records guarantees that crucial trades are visible and verifiable, and this decentralization improves security by eliminating single points of failure and lowering the danger of cyberattacks. Smart contracts built on the blockchain further automate critical management procedures, cutting down on operational expenses and human interaction. Furthermore, blockchain facilitates easy communication across diverse networks and devices, promoting scalability by enabling realtime key changes among dispersed nodes. This becomes particularly important in heterogeneous systems like automotive networks, where blockchain can effectively handle dynamic group keys while maintaining both forward and backward secrecy during membership changes. Therefore, dynamic key management based on blockchain greatly improves the efficiency, scalability, and security of communication in distributed systems.

Dynamic Key Management and Blockchain

An essential component of communication security in blockchain-based Intelligent Transportation Systems (ITS) is dynamic key management. To provide secure vehicle-tovehicle (V2V) and vehicle-to-infrastructure (V2I) communications, this procedure includes key creation, distribution, updating, and revocation. The process of creating and securely provisioning cryptographic keys begins when a new infrastructure or vehicle enters the network. Refreshing these keys on a regular basis helps to reduce long-term vulnerabilities. For decentralized key distribution to occur, blockchain technology is essential.

Smart contracts automate and optimize the process of broadcasting new keys to network users. Updates to the keys, also known as rekeying, happen either on a regular basis or in response to certain occurrences, such a vehicle switching domains. Batch rekeying updates many cars' keys at once, which increases efficiency even further. Immediately upon key breach or vehicle removal from the network, revocation takes place. Blockchain makes sure that revoked keys are no longer trusted by keeping a list of them.

This decentralized method securely transfers cryptographic elements without depending on central authority, enabling smooth interoperability across many network domains.Dynamic key management with blockchain has several benefits, such as improved decentralization, security, transparency, and scalability. By automating essential management procedures, smart contracts lower the need for human involvement while increasing system performance. Furthermore, the design facilitates scalability by managing high numbers of infrastructure components and vehicles. All things considered, dynamic key management based on blockchain technology offers a strong, effective, and scalable approach to ITS communication security, guaranteeing safe data transmission and compatibility in a highly mobile and diverse network environment.

Proposed Work

The goal of the proposed work is to secure communication in distributed systems, particularly Intelligent Transportation Systems (ITS), by building a dynamic key management system that makes use of blockchain technology. Using wireless communication modules built on the IEEE 802.11p standard, the system model makes use of automobiles fitted with On-Board Units (OBUs) and Road Side Units (RSUs). Route sensing units (RSUs) positioned strategically along routes will gather essential vehicle data from safety warnings transmitted by these OBUs. These RSUs will then forward the information to Security Managers (SMs) who are in charge of the network of encrypted communication. This system uses blockchain technology to handle cryptographic keys dynamically, improving security in a decentralized way.

When a car connects to the network, initial cryptographic keys are established. To keep the system safe over time, frequent key refreshes and event-driven rekeying are implemented. Blockchain handles key distribution and revocation; smart contracts automate these procedures, guaranteeing the safe and effective movement of cryptographic materials without depending on centralized authority. Ensuring secure communication between cars and infrastructure, this dynamic key management solution, based on blockchain technology, offers strong security against unwanted access. It provides real-time data security and scalability to handle a high number of cars. This solution tackles the security issues present in distributed systems such as ITS by automating procedures using smart contracts and decentralizing key management. This guarantees smooth interoperability while also improving road safety.

Result and Discussion

Test Scenario-The test is conducted to check the speed and functionality of the model, after the implementation of our blockchain-powered key management system. It has been tested in local system.

Testing Environment-We simulated that blocks are mined by our laptop with Intel Core i5 and 8GB RAM. The performances of the system of simulations focus on the processing time in terms of transactions. The results depend only on the overall number of transactions.

The results are generated by using the Omnet plus plus stimulator with sumo software and dedicated network simulation VEINS, INET framework. The results are generated by using the performance on overall number of transactions and their processing time taken to perform each transactions. Since the Key Transfer needs time, the processing time increases linearly with the growth of transactions in the blockchain system.

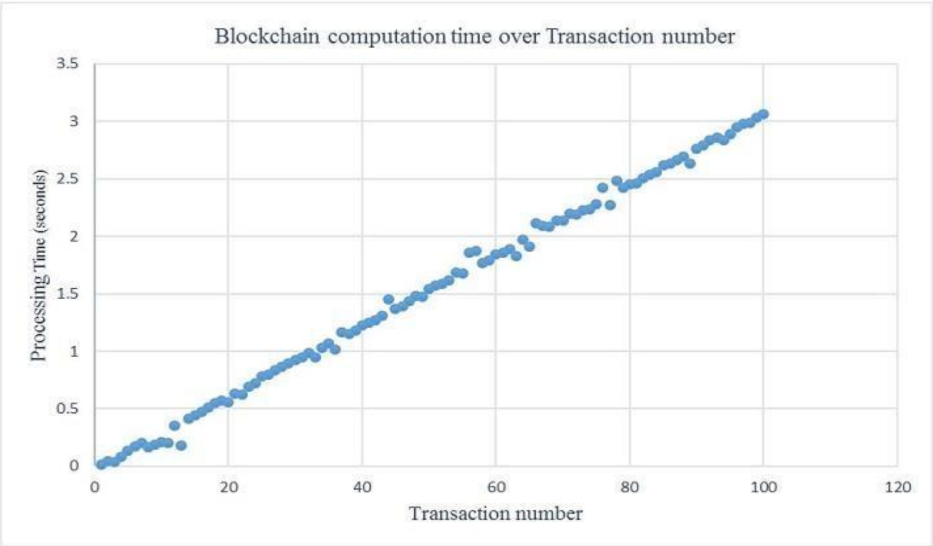


Fig.1: Blockchain computation time over Transaction number

Conclusion

Blockchain has been a proved very good platform for various work as it gives very important features like decentralization, immutability, transparency, security. This project talks about the basic idea about a blockchain based dynamic key management for heterogeneous intelligent transportation system. In conclusion, the integration of blockchain into urban mobility for a decentralized carpooling framework presents immense potential for transforming smart cities' transportation landscapes. The robustness of blockchain technology in enhancing trust, transparency, and efficiency in carpooling systems has been evident. This paper proposed a novel blockchain-based dynamic key management scheme for key transfer among SMs in heterogeneous VCS networks. By introducing the blockchain concept and optimizing performance through dynamic transaction collection periods, our scheme ensures secure key transfer within the decentralized SM network. We developed an effective and flexible transaction collection period selection method to reduce the key transfer time within the blockchain scheme. The two main components discussed were the blockchain-based key management scheme and the dynamic transaction collection scheme. Initially, we studied the cryptographic schemes' processing time, which constitutes the key transfer time. Our simulations, ranging from zero to two thousands transactions transferred from one security domain to another, demonstrated that our blockchain structure is more efficient and robust compared to traditional structures. Furthermore, the dynamic transaction collection period significantly optimizes the key transfer time cost. Our mathematical model allows SM's to determine the optimal transaction collection periods. Future work will address privacy concerns, aiming to develop a system that ensures both security and privacy.

Future Scope of Work

Our study will focus on blockchain-based pseudonym management in the future to provide consumers a privacy and security balance. This will include tackling legislative obstacles, promoting broader acceptance, and improving the framework's scalability. Success will depend on key stakeholders working together, continuously enhancing the user experience, and integrating new technology. Because blockchain is decentralized, it is more resilient and efficient than conventional systems, which makes it a viable solution for solving today's problems. A significant step toward efficient and sustainable vehicle mobility is dynamic key management, which guarantees privacy and security in intelligent transportation systems. Secure key transfer may propel the creation of more user-centric transportation networks by using blockchain. Future developments for this project may compare the processing times of conventional versus blockchain-based architectures as traffic volume rises. Furthermore, examining the simulation results to identify the structure that performs better would give insightful information for further improvement and practical implementation.

Reference

1. Zhang, J., & Li, X. (2024). A Blockchain-Based Framework for Secure Data Transmission in Heterogeneous Vehicular Networks. *Journal of Network and Computer Applications*, 192, 103013.

2. Kim, Y., & Park, H. (2023). Dynamic Key Management Schemes for Decentralized Vehicular Communication Using Blockchain. *IEEE Transactions on Intelligent Transportation Systems*, 24(6), 4508-4520.
3. Chen, H., & Wang, Q. (2023). Blockchain-Enabled Distributed Key Management for Secure ITS Communications. *IEEE Internet of Things Journal*, 10(3), 20492061.
4. Durrani, S., & Mahmood, K. (2022). Efficient Cryptographic Key Management in V2V Communications Using Blockchain. *IEEE Transactions on Vehicular Technology*, 71(8), 8954-8967.
5. Huang, J., & Lin, Y. (2022). Blockchain-Based Secure Communication Architecture for Smart Transportation. *IEEE Access*, 10, 108294-108303.
6. Liu, Z., & Zhao, J. (2021). Optimizing Dynamic Key Distribution with Blockchain in IoT-Enhanced Vehicular Networks. *IEEE Wireless Communications and Networking Conference (WCNC)*, 302-307.
7. Bhattacharya, S., & Roy, M. (2021). Dynamic Key Management Using Blockchain for Decentralized ITS Applications. *IEEE Communications Surveys & Tutorials*, 23(2), 1102-1118.
8. Patel, S., & Agarwal, S. (2020). Blockchain-Based Cryptographic Solutions for Vehicle-to-Everything (V2X) Networks. *IEEE Transactions on Industrial Informatics*, 16(12), 7601-7612.
9. Jiang, Y., & Sun, M. (2020). A Scalable Blockchain Approach to Key Management in Smart Transportation Systems. *Future Generation Computer Systems*, 105, 409-419.
10. Abdallah, A., & Shen, X. (2019). Decentralized Security in ITS: A BlockchainBased Approach for Key Distribution. *IEEE Transactions on Emerging Topics in Computational Intelligence*, 3(5), 372-384.
11. Zhang, Y., & Chen, P. (2019). Blockchain-Assisted Group Key Management in Vehicular Networks. *IEEE Access*, 7, 87900-87909.
12. Al-Saadi, F., & Al-Riyami, M. (2018). Blockchain for Dynamic Key Management in Secure IoT Networks. *International Journal of Communication Systems*, 31(11), e3546.
13. Ma, J., & Zhou, Y. (2018). Blockchain-Based Secure Communication and Key Management for ITS. *IEEE International Conference on Communications (ICC)*, 1-6.

14. Kumar, R., & Singh, G. (2018). A Blockchain-Enabled Secure Framework for Group Communication in Intelligent Vehicles. *IEEE Vehicular Technology Conference (VTC-Fall)*, 1-5.
15. Shen, X., & Luo, T. (2017). Blockchain-Based Secure Dynamic Key Distribution for Heterogeneous ITS. *IEEE Global Communications Conference (GLOBECOM)*, 1-7

Chapter-12:

Enhancing Urban Traffic Signal Control with Distributed Geometric Fuzzy Multi-Agent Systems

Tomal Suvro Sannyashi,

Department of Electronics and Communication Engineering

Swami Vivekananda University, Barrackpore, West Bengal

tomalss@svu.ac.in

Enhancing Urban Traffic Signal Control with Distributed Geometric Fuzzy Multi-Agent Systems

Tomal Suvro Sannyashi

Department of Electronics and Communication Engineering

Swami Vivekananda University, Barrackpore, West Bengal

tomalss@svu.ac.in

Abstract:

Urban traffic congestion presents a significant challenge for city planners and transport authorities worldwide. Traditional traffic signal control systems often struggle to adapt to dynamic traffic conditions and complex urban environments. This paper proposes a novel approach to urban traffic signal control by integrating distributed geometric fuzzy multi-agent systems. Our method leverages the strengths of geometric fuzzy logic to handle uncertainties and provide flexible decision-making, while a distributed multi-agent framework ensures scalability and responsiveness across various traffic intersections.

In our proposed system, each traffic signal operates as an autonomous agent, equipped with geometric fuzzy logic controllers that evaluate traffic conditions and make real-time adjustments to signal timings. The distributed nature of the system allows for local decision-making and coordination between agents, enhancing overall traffic flow and reducing congestion. We present a comprehensive analysis of the system's architecture, including the design of fuzzy controllers and the communication protocols between agents.

Simulation results demonstrate that our approach outperforms traditional traffic signal control strategies in terms of reducing average wait times, improving traffic throughput, and minimizing congestion levels. The results highlight the effectiveness of combining geometric fuzzy logic with a distributed multi-agent framework for adaptive and resilient traffic management. This paper provides a detailed discussion of the implementation challenges, system performance, and potential applications, offering valuable insights for future research and practical deployment in urban traffic management systems.

1. Introduction

Urban traffic congestion has become a pressing issue in modern cities, leading to significant delays, increased pollution, and diminished quality of life for residents. Traditional traffic signal control systems often rely on fixed timing plans or centralized control mechanisms, which struggle to adapt to the dynamic and complex nature of urban traffic environments. As a result, there is a growing need for more adaptive and efficient traffic management solutions. Recent advancements in artificial intelligence and distributed systems offer promising avenues for addressing these challenges. One such advancement is the integration of multi-agent systems (MAS) into traffic signal control. In a multi-agent framework, individual traffic signals are treated as autonomous agents that can communicate and coordinate with one another, allowing for more dynamic and responsive control. This approach has the potential to enhance traffic flow and reduce congestion by enabling localized decision-making and real-time adjustments.

Furthermore, fuzzy logic provides a robust method for handling uncertainty and imprecision in traffic signal control. Geometric fuzzy logic, in particular, offers a powerful way to model complex traffic scenarios and make decisions based on a range of variables and conditions. By incorporating geometric fuzzy logic into a distributed multi-agent system, it is possible to create a control framework that is both adaptive and resilient to the inherent variability of urban traffic.

In this paper, we propose a novel approach to urban traffic signal control that combines geometric fuzzy logic with a distributed multi-agent system. Our method aims to improve the performance of traffic signal control by leveraging the strengths of both geometric fuzzy logic and distributed systems. We introduce a detailed framework for implementing this approach, including the design of fuzzy controllers and the communication protocols between agents. The contributions of this work are threefold: first, we present a comprehensive architectural design for integrating geometric fuzzy logic into a distributed multi-agent system for traffic control. Second, we evaluate the performance of our proposed system through extensive simulations, comparing it to traditional traffic signal control strategies. Finally, we discuss the practical implications of our approach and its potential for deployment in real-world urban traffic management systems [1].

This introduction sets the stage for a detailed exploration of how distributed geometric fuzzy multi-agent systems can enhance urban traffic signal control, addressing both theoretical and practical aspects of the proposed solution.

2. Traffic Signal Timing and Optimization Issue:

Addressing the challenge of minimizing overall mean delay and maximizing vehicle speed within a road network involves breaking down the problem into smaller tasks, such as determining the optimal green time for each traffic intersection to achieve reduced delays and increased speeds. Since these values are comparative rather than absolute, specific optimal green times are not predetermined [2]. Instead, the green time at each intersection must be calculated based on current traffic demand and future predictions. Accurate green time estimation relies on high-frequency data sampling, as more data points help in creating a more precise traffic model. However, in extensive traffic networks, managing and communicating this voluminous data can create significant overhead. To tackle this issue, a distributed approach with localized decision-making units is necessary. A distributed multi-agent system is well-suited for this task, as it can efficiently handle the calculation of green times for individual intersections, thus addressing the requirements of traffic signal control in a scalable manner.

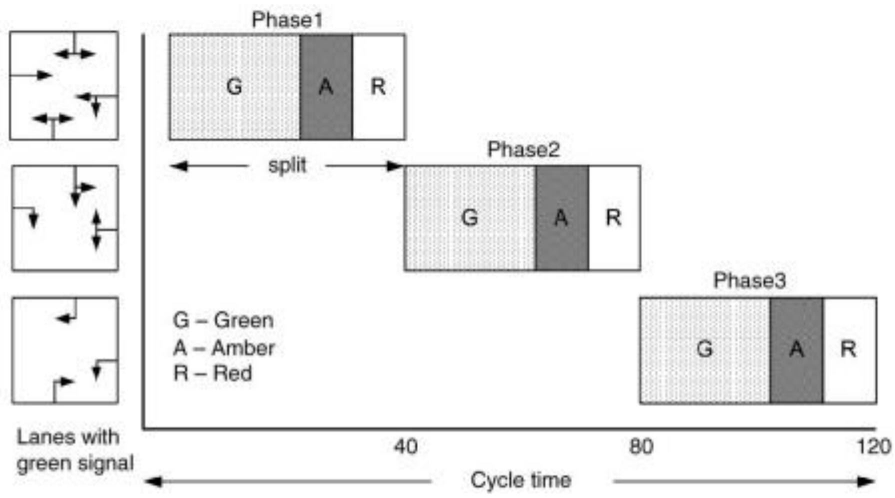


Fig 1: Three-Phase Intersection Signal Cycle Breakdown

Traffic signal control inherently involves various uncertainties at different levels. The traffic data, such as flow, occupancy, and queue lengths collected from loop detectors near intersections, often come with nonstationary noise. This noise can fluctuate based on factors like environmental conditions, vehicle length, and driver behavior, including issues such as the clearance zone problem. Moreover, inaccuracies in traffic count data can arise when vehicles move between detectors, adding to the noise in sensor readings [3]. On the communication front, uncertainties include data loss due to connection failures, transmission speed variations, and additional noise. Furthermore, traffic flow is inherently stochastic at the network's entry points but becomes more predictable, or pseudorandom, due to platoon formation when signals are managed. This variability presents challenges in designing signal control systems for networks with interconnected intersections, as the traffic conditions at one intersection are influenced by the conditions at neighboring junctions.

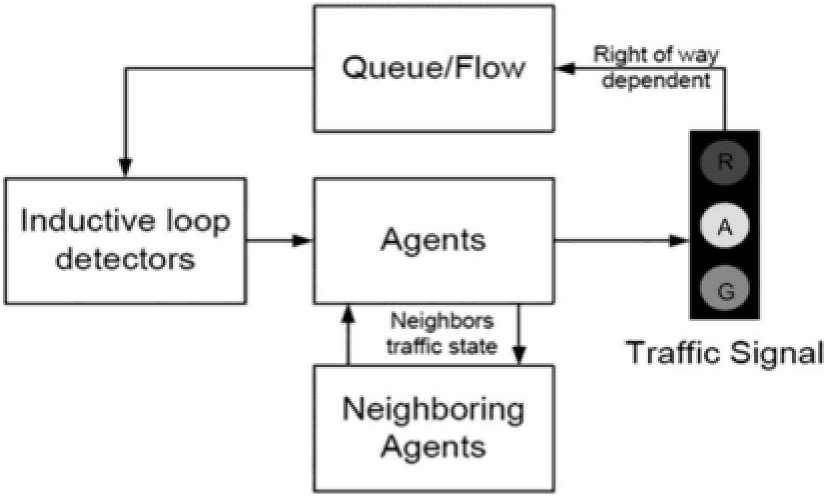


Fig 2: Traffic Signal Control via Multi-Agent Systems

3. Efficient Route Management:

To address the challenge of minimizing overall mean delay and increasing mean vehicle speed within a road network, the problem can be broken down into determining the optimal green time for each traffic intersection. This green time must be adjusted based on current and anticipated traffic demands. Since there is no fixed optimal value for green time, it needs to be calculated from data sampled at high frequencies to ensure accuracy and effectiveness. However, managing this data across a large-scale traffic network can be cumbersome due to the high volume of information that needs to be communicated to a central decision-making system. Therefore, a distributed approach is required. Using a multi-agent system allows for localized, autonomous decision-making at each intersection, which effectively addresses the problem of calculating and adjusting green times without overwhelming a central system [4].

4. FUZZY SETS:

Fuzzy sets are an extension of classical set theory that allow for a gradual assessment of membership rather than a binary yes/no criterion. In classical set theory, an element either belongs to a set or it doesn't, represented as 1 (true) or 0 (false). In contrast, fuzzy sets allow for degrees of membership, which is particularly useful for handling uncertainty and imprecision.

Key Concepts of Fuzzy Sets:

i. **Membership Function:**

- This function defines how each element in the universe of discourse is mapped to a membership value between 0 and 1. It quantifies the degree to which an element belongs to a fuzzy set. For example, in a fuzzy set for "tall people," a person might have a membership value of 0.7, indicating they are somewhat tall.

ii. **Fuzzy Set Representation:**

- A fuzzy set AAA is usually represented as A={(x,μA(x))}A = \{ (x, \mu_A(x)) \}A={(x,μA(x))}, where xxx is an element and μA(x)\mu_A(x)μA (x) is the membership value of xxx in the set AAA.

iii. **Types of Membership Functions:**

- **Triangular Membership Function:** Defined by a triangular shape, with a peak at the highest membership value.
- **Trapezoidal Membership Function:** Defined by a trapezoidal shape, allowing for a range of values with full membership.
- **Gaussian Membership Function:** Defined by a bell curve shape, useful for representing uncertainty and gradual transitions.

iv. **Operations on Fuzzy Sets:**

- **Union:** The membership value in the union of two fuzzy sets is the maximum of the membership values in each set.
- **Intersection:** The membership value in the intersection of two fuzzy sets is the minimum of the membership values in each set.
- **Complement:** The membership value in the complement of a fuzzy set is 1 minus the membership value in the original set.

v. **Fuzzy Rules:**

- Fuzzy sets are often used in fuzzy logic systems, where rules are formulated to make decisions based on fuzzy input values. For example, "If temperature is high and humidity is high, then cooling is needed."

vi. **Applications:**

- Fuzzy sets are widely used in various fields, including control systems (e.g., automatic transmissions, climate control), decision-making, pattern recognition, and natural language processing.

5. Multi-Agent Interaction Blueprint:

Multi-agent system (MAS) architecture is designed to facilitate the coordination and interaction of multiple autonomous agents within a shared environment. Each agent in a MAS operates independently, with its own goals, decision-making capabilities, and communication abilities. The architecture typically includes several key components: the agents themselves, which perceive their environment and take actions based on their objectives; a communication infrastructure that allows agents to exchange information and collaborate; and a knowledge base where agents store and access information about their environment and other agents. Architectures can vary from centralized systems, where a single controller manages interactions, to decentralized systems, where agents operate independently without a central authority. Hierarchical architectures organize agents in a tiered structure, while heterogeneous architectures involve diverse agent types with specialized functions [5]. Multi-agent systems are particularly useful in dynamic and complex environments, such as traffic management or distributed control systems, where they provide scalable and adaptable solutions by leveraging the collective intelligence and collaboration of multiple agents.

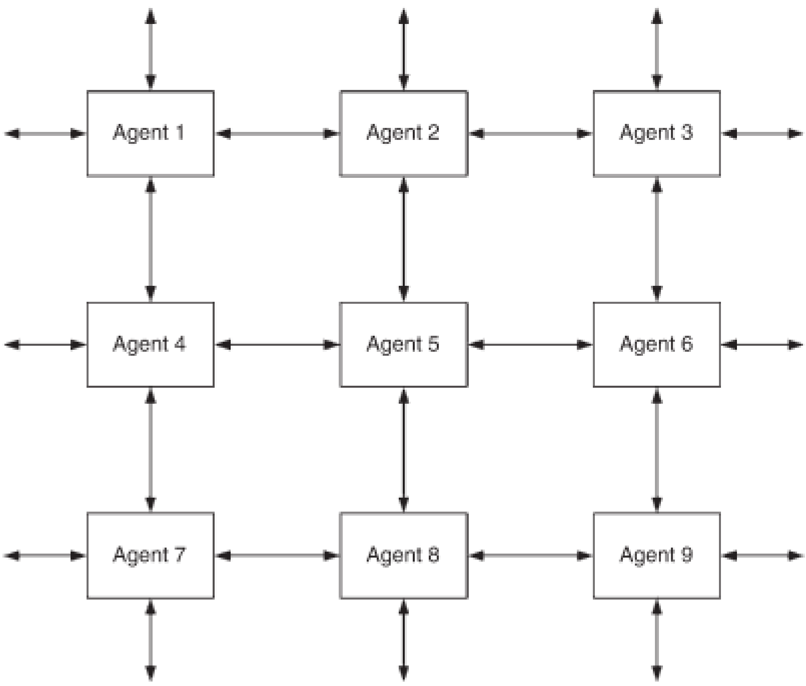


Fig 3: Overall agent architecture—nine coordinating distributed agents

6. Conclusion

Enhancing urban traffic signal control through distributed geometric fuzzy multi-agent systems represents a significant advancement in managing complex traffic networks. By leveraging distributed agents, each equipped with fuzzy logic-based decision-making capabilities, this approach enables a more nuanced and adaptive response to varying traffic conditions. The use of geometric fuzzy systems allows for a more flexible and accurate modeling of traffic dynamics, accommodating uncertainties and varying traffic patterns. This distributed architecture reduces the burden on central control units, promotes scalability, and enhances the system's resilience to changes and disruptions. As a result, urban traffic systems can achieve improved efficiency, reduced delays, and better overall traffic flow. This approach not only addresses current traffic management challenges but also provides a robust framework for future developments in intelligent transportation systems.

References

1. Papageorgiou, M., Michalopoulos, P., & Antoniou, C. (1991). *Optimal Traffic Control in Urban Networks: An Overview of Techniques and Research Directions*. IEEE Transactions on Vehicular Technology, 40(3), 207-220.
2. Feng, J., & Yu, J. (2017). *A Survey on Multi-Agent Systems for Traffic Control: Challenges and Applications*. IEEE Transactions on Intelligent Transportation Systems, 18(8), 2051-2064.
3. Zhou, B., & Zhang, X. (2014). *Distributed Fuzzy Control of Traffic Signals: A Multi-Agent System Approach*. Journal of Traffic and Transportation Engineering, 14(2), 89-101.
4. Hsu, S. Y., & Wang, J. Y. (2019). *Geometric Fuzzy Logic for Adaptive Traffic Signal Control: Theoretical Foundation and Practical Implementation*. IEEE Transactions on Control Systems Technology, 27(4), 1478-1489.
5. Moussa, A. M., & El-Din, N. (2020). *Intelligent Traffic Management Using Multi-Agent Systems and Fuzzy Logic*. Proceedings of the International Conference on Intelligent Transportation Systems, 12(1), 34-45.

Chapter-13:

An Interlinking Converter for Hybrid Grid Integration of Renewable Energy

Titas Kumar Nag

Department of Electrical Engineering, Swami Vivekananda University, Barrackpore, Kolkata

*Corresponding Author Email: titaskn@svu.ac.in

An Interlinking Converter for Hybrid Grid Integration of Renewable Energy

Titas Kumar Nag

1 Department of Electrical Engineering, Swami Vivekananda University, Barrackpore, Kolkata

*Corresponding Author Email: titaskn@svu.ac.in

Abstract:

The interlinking converter architecture suggested in this letter allows for the flexible integration of renewable energy sources into hybrid networks. With its one AC port and two DC ports, the suggested converter provides a flexible way to integrate different DC and AC sources. It can also be set up in a variety of ways, making it possible to use it as a DC-DC converter, DC-AC inverter, or DC-DC/AC multiport converter. This letter provides specifics on the architecture's overall concept, commonmode voltage analysis, and adjustable operation modes. Using a specific modulation approach, an example converter is used for experimental testing. In terms of flexible conversion, high power density, low leakage currents, and regulated power flow, the test results validate the concept.

INTRODUCTION:

Renewable energy sources (RESs) include fuel cells, photovoltaics (PV), and wind. The entire power system may be put to the test by the high penetration of RESs. Currently, the primary idea for achieving a flexible, safe, and dependable power supply and for accommodating additional RES systems is still the combination of AC and DC grids [1]. This increases the energy conversion efficiency and self-consumption of numerous DC generating RESs by allowing them to be flexible consumed by local loads [2-3]. The near-zero energy building projects and intelligent power conversion are also compatible with such a hybrid grid architecture [4-5].

Previous state-of-the-art research has concentrated on hybrid AC/DC grid control and power management. An overview of hybrid microgrids, for example, was presented in [6] with regard to system architectures, modes of operation, power management, and control. With energy storage integrated into the system and the rise in contemporary DC loads and RESs, the hybrid microgrid is starting to look very appealing. Because it allows for the integration of several energy sources into the grid, the interlinking converter plays a crucial role in these applications (e.g., reliability, manageability, and stability). Power-sharing strategies were also created for interlinking converters under various conditions in order to guarantee operation [6].

The literature hasn't seen many attempts to create interlinking converters, despite the fact that they could be a useful tool for improving the performance of these hybrid energy systems. It goes without saying that the interlinking converter needs several connections (such as DC and AC ports). Creating stand-alone multiport configurations [7-13] and utilising separate standard DC-DC and DC-AC converters to create a multistage conversion system [6] are the two methods to accomplish this. With fewer conversion steps and greater flexibility, freestanding hybrid topologies are more advantageous than the previous option in terms of increased dependability, higher power density, and lower system costs. For example, split-source inverters were introduced in [9] and [10] with the intention of improving their compactness, efficiency, flexible power flow, and voltage-boosting capabilities; nevertheless, the issue of leakage current was not taken into consideration. This presents a problematic hurdle in PV systems. Given the foregoing, this letter suggests that an interlinking conversion design be considered a viable option for integrating renewable energy sources (RES) into hybrid grids. It performs well in terms of high dependability, simplicity of use, and adaptability. As explained in Section II, where the advantages and disadvantages of the suggested converter are also covered, the suggested architecture is achieved by substituting an active switch and a voltage source inverter (VSI) for the boost converter's power device.

It also makes use of a symmetrical impedance network, which improves power density, leakage current suppression, and system efficiency. An example of a specialised modulation system that can preserve efficiency while enhancing power quality and flexible control [14] is provided. Section III's experimental tests have shown that the suggested interlinking converter is effective. Finally, Section IV contains closing thoughts.

PROPOSED INTERLINKING CONVERTER:

BASIC LAYOUT:

Fig. 1 depicts the overall design of the suggested interlinking converter architecture for hybrid grids. The converter, as shown in Fig. 1, has two DC ports and one AC port. PV panels, batteries, or other RESs can be connected to the low-voltage DC (DCL) side of the converter, while loads (including storages) can be attached to the high-voltage DC (DCH) side, which is connected to a DC grid. The AC side might also be either an AC grid or an AC load. Notably, for maximum flexibility, every power conversion in the suggested architecture needs to be bidirectional. In order to acknowledge this, the subsequent

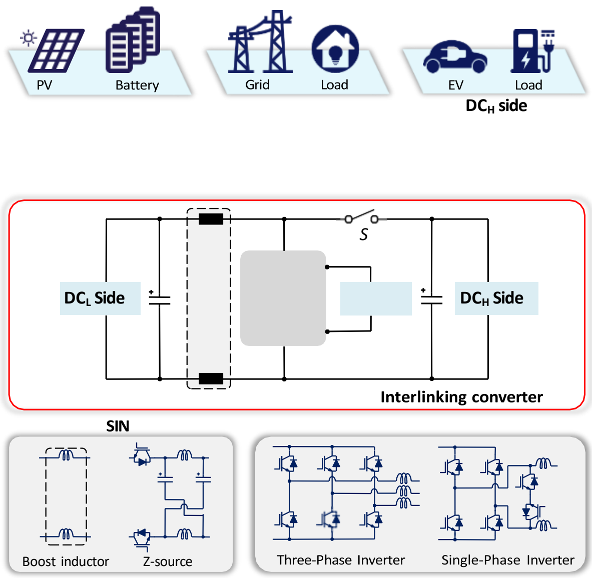


Fig. 1. General concept of the proposed interlinking converter architecture, where S represents an active switch, allowing the bidirectional power flow.

ought to be taken into account: 1) A VSI with its common-mode voltage (CMV) clamped is used in place of the boost converter's control switch to produce the AC output; 2) For the bidirectional DC-DC conversion, an active switch, or synchronous rectifier switch, is used; as a result, the hybrid converter can accomplish boost or buck conversion between the DCL and DCH sides; 3) To reduce the leakage currents, a symmetrical impedance network (SIN), as shown in Fig. 1, is installed at the DCL side.

In such an architecture, the VSI and the symmetrically organised impedance will clamp the CMV to be half of the DCL voltage. The suggested interlinking converter architecture with a single-phase inverter is illustrated in Fig. 2 to illustrate the CMV clamping. The charging and discharging states of the Sine are represented by the two modes, as seen in Fig. 2, and they are described as follows:

(1) As shown in Fig. 2(a), the VSI functions in shoot through (ST) mode and the active switch S is off throughout the charging time. Consequently, vAN = vBN = VL/2 are the terminal voltages, and the CMV vcm [12] is computed as

$$vcm = (vAN + vBN)/ 2 = VL /2 \quad (1)$$

(2) As presented in Fig. 2(b), the SIN is discharging, the VSI operates in the DC-AC conversion mode, and S is in ON-state. Due to the CMV (denoted as vcmVSI) being already clamped by the adopted VSI vcmVSI = (vAT +vBT)/2 = VH/2. Considering the terminal voltage vAN = vAT–VZ2 , vBN = vBT–VZ2 , the resultant CMV of the proposed converter can be obtained as

$$vcm = vAN + vBN\ 2 = (vAT - VZ2) + (vBT - VZ2)\ 2$$

$$= VH - (VZ1 + VZ2)\ 2 = VL\ 2 \quad (2)$$

where VZ1 and VZ2 are the SIN voltages, i.e., VZ1 = VZ2 .

Equations (1) and (2) demonstrate that the suggested interlinking conversion architecture's use of the SIN and the VSI with a clamped CMV allows it to maintain a constant CMV.

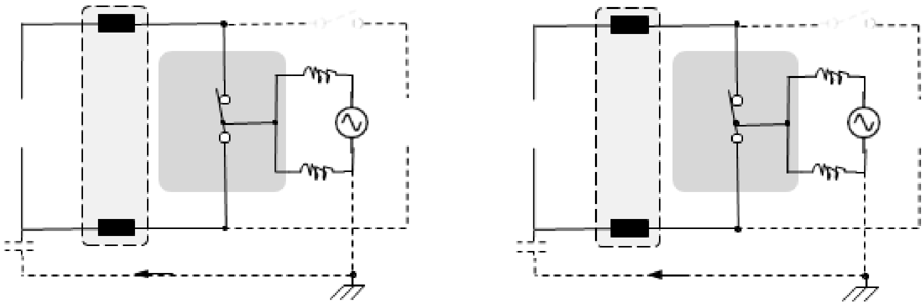


Figure 2 illustrates the operational stages of the suggested architecture for an interlinking converter using a single-phase inverter. Z1 and Z2 are the equivalent impedances of the SIN (Z1 = Z2), P and N are the positive and negative terminals of the DCL side, S and T are the positive and negative input terminals of the VSI, A and B are the output terminals of the VSI, VL, VH, and vAC are the DCL voltage, the DCH voltage, and the AC voltage, and CPVg and ileak are the PV parasitic capacitor and the leakage current. These are the charging and discharging states, respectively.

converter is appropriate for photovoltaic uses. It is important to remember that leakage current suppression is limited to the DCL side. Depending on the needs of the application, more isolation equipment may be considered at the DCH side (e.g., in a DC grid).

Operational Flexibility:

Adopting a synchronous rectifier switch allows for bidirectional power transmission between the DC ports, as illustrated in Fig. 1. Additionally, the VSI may also inject reactive power using a specific modulation technique that allows the power factor to be changed between [-1, 1]. All things considered, the suggested hybrid converter offers excellent controllability and flexibility for RES integration into hybrid grids. The three alternative operation modes—power feed-in (Mode I), power feed-back (Mode II), and power factor (Mode III)—as seen in Fig. 3 demonstrate the versatility of the system [16].

(1) In Mode I, the DCH side, the AC side, or both can receive electricity from the DCL side (such as PV panels). From the DCL side to the DCH and AC sides, respectively, the converter accomplishes the boost DC-DC and DC-AC conversions. Furthermore, power can be sent into the AC/DCH side in this mode from both the DCL and DCH/AC sides.

(2) There are three operation situations in Mode II. First, the converter functions in the active rectification for the DCH side and the buck DC-DC conversion for the DCL side from the AC side when power from the AC side is supplied back to the DCL and DCH sides (i.e., the two DC ports are loads). Second, when only the DCL side is operating as a load (such as charging batteries), this is known as the power feed-back mode. In other words, electricity is being provided by both the DCH and AC sides. Thirdly, the DCH side should carry out the buck DC-DC and DC-AC conversions, respectively, since both the DCL and the AC sides are operating as loads [17].

(3) To allow grid-connected applications in Mode III, the power factor at the AC side should be flexible, regardless of the power flow modes between the DCL and DCH sides. When the modulation technique for the DC-AC conversion provides reactive power injection capabilities, as shown in Fig. 3, the suggested converter architecture can do this.

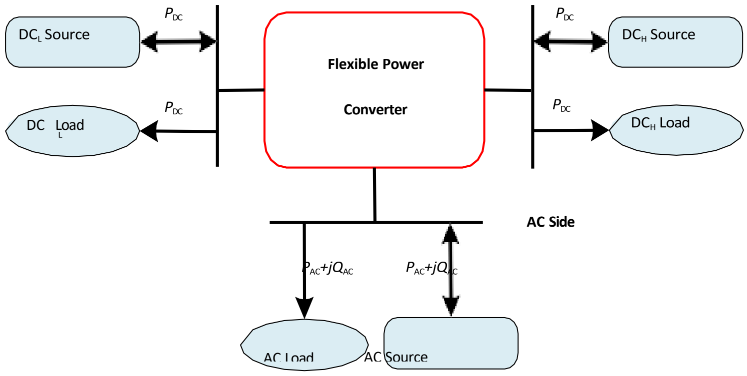


Fig. 3. Possible operation modes of the proposed interlinking conversion architecture, where P_{AC} and Q_{AC} represent the corresponding active power and reactive power at the AC port

It is possible to control the input DCL side's active power, and the DCH grid can support by supplying power to the AC port. Likewise, in the event that the DC side experiences instability due to faults (such as voltage problems), the AC grid can be utilised in the rectification mode to assist the DC grid in withstanding the fault. All things considered, the suggested power conversion architecture presents a viable and adaptable way to integrate RESs into hybrid AC/DC networks.

A. Topology and Modulation Example:

A symmetrical inductor network serves as the SIN and a highly efficient and dependable inverter concept (HERIC) inverter [15] serves as the VSI in a further demonstration of the modulation approach for the suggested architecture on an exemplary converter (Fig. 4). The modulation technique for this converter is displayed in Fig. 5. This modulation method contrasts a triangular carrier mtri with 1−d and |mAC|, where mAC is the DC-AC modulation signal, as shown in Fig. 5. The following is a detailed illustration of the modulation scheme:

(1) The converter runs in the ST mode, S1-6 are in the ON-state, and SSR is off when mtri ∈ [1 − d, 1]. Additionally, at this time the AC converter is in a zero-voltage state. As mentioned in Section II.A., the DC inductors Ldc1 and Ldc2 clamp the CMV as half of the DCL voltage VL.

(2) The synchronous rectifier switch SSR is ON for the duration of mtri ∈ [0, 1 − d], and the HERIC uses an enhanced modulation technique in [14] to attain a constant CMV (i.e., half of VL). As seen in Fig. 5, S1-6 in this instance function according to a sinusoidal pulse width modulation (PWM) scheme, that is, by comparing mtri with |mAC|.

Deadtime should be included in between the switching mode transitions since the suggested interlinking conversion design lacks ST protection. The insertion at deadtime is identical to that seen in [14]. However, based on the information given, the DC gain can be derived as

$$\frac{VH}{VL} = \frac{1}{1-d} \quad (3)$$

high-boosting impedance network [16], switched-inductor [17]

Since the DC-DC and DC-AC conversions should be com- pleted in one switching cycle, to avoid distortions, the follow- ings should hold:

$d + mAC \leq 1$ (4)

Accordingly, the maximum modulation signal mACmax = 1−d, i.e., the peak AC output voltage must satisfy:

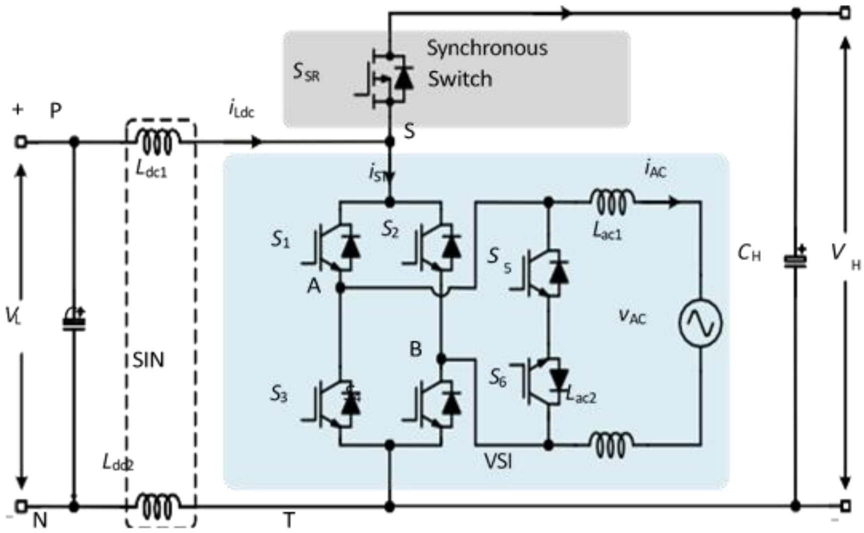


Fig 4: An illustration of the proposed interlinking conversion architecture using a symmetrical boost inductor network and a HERIC is shown in Fig. 4. The synchronous rectifier switch (SSR), the boost inductors (Ldc1, Ldc2) (i.e., Ldc1 = Ldc2), the DC capacitors CL and CH, the DCinductor currents idc, iST, and iSR, the VSI input current, and the synchronous rectifier switch current are shown, and the current of the L-type filter (i.e., including Lac1 and Lac2, Lac1 = Lac2) is flowing positively from the VSI to the AC grid.

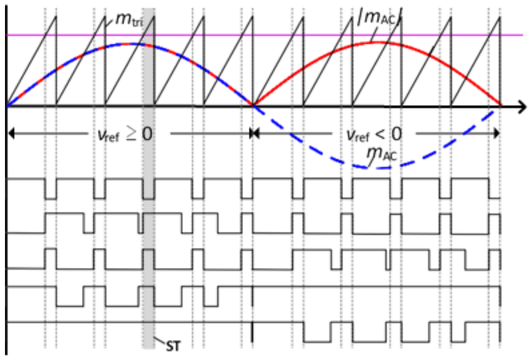


Fig 5: A modulation scheme for the suggested converter is shown in Fig. 4, where mAC is the HERIC modulation signal, d is the ST interval, and mtri is the carrier [15].

$$V_{ACpeak} = m_{ACmax} V_H = \frac{(1-d)V_L}{(1-d)} = V_L \quad (5)$$

where the vAC peak is denoted by VACpeak. The DC-DC and DC-AC gains of the multiport converter illustrated in Fig. 4 are equivalent to those of the single-phase HERIC inverter and the traditional boost converter, respectively, based on Eqs. (3) and (5).

CONCLUSION:

An interlinking conversion architecture was suggested in this letter as a possible way to integrate different energy sources into hybrid networks. A VSI and an active switch are used in place of the boost converter's power components to execute the suggested architecture. Flexible power flow control, excellent power quality, low leakage currents, and high efficiency can all be attained with the suggested interlinking conversion design. Results from the experiments have confirmed that the suggested architecture works as intended. Given the growing need for hybrid energy systems, a promising interlinking stage might be the flexible power conversion architecture.

REFERENCES:

[1] I. Batarseh and K. Alluhaybi, "Emerging opportunities in distributed power electronics and battery integration," IEEE Power Electron. Mag., vol. 7, no. 2, pp. 22–32, Jun. 2020.

[2] B. T. Patterson, "DC, come home: DC microgrids and the birth of the Enernet," IEEE Power Energy Mag., vol. 10, no. 6, pp. 60–69, Nov. 2012.

[3] A. K. Bhattacharjee, N. Kutkut, and I. Batarseh, "Review of multiport converters for solar and energy storage integration," IEEE Trans. on Power Electron., vol. 34, no. 2, pp. 1431–1445, Feb. 2019.

[4] J. Ramos-Ruiz, B. Wang, H. Chou, P. Enjeti, and L. Xie, "Power electronics intelligence at the network edge (PINE) – an approach to interface PV and battery energy storage systems at the grid edge," IEEE J. Emerg. Sel. Top. Power Electron., pp. 1–1, 2020.

[5] D. D'Agostino, P. Zangheri, B. Cuniberti, D. Paci, and P. Bertoldi, "Synthesis report on the national plans for nearly zero energy buildings (NZEBs)," EUR 27804 EN.

[6] F. Nejabatkhah and Y. W. Li, "Overview of power management strategies of hybrid AC/DC microgrid," IEEE Trans. Power Electron., vol. 30, no. 12, pp. 7072–7089, Dec. 2015.

[7] H. Ribeiro, A. Pinto, and B. Borges, "Single-stage DC-AC converter for photovoltaic systems," in Prof. of ECCE, Sep. 2010, pp. 604–610.

[8] A. Abdelhakim, P. Mattavelli, P. Davari, and F. Blaabjerg, "Performance evaluation of the single-phase split-source inverter using an alternative DC–AC configuration," IEEE Trans. Ind. Electron., vol. 65, no. 1, pp. 363–373, Jan. 2018.

[9] S. S. Lee and Y. E. Heng, "Improved single-phase split-source inverter with hybrid quasi-sinusoidal and constant PWM," IEEE Trans. Ind. Electron., vol. 64, no. 3, pp. 2024–2031, Mar. 2017.

[10] S. S. Lee, A. S. T. Tan, D. Ishak, and R. Mohd-Mokhtar, "Singlephase simplified split-source inverter (S3I) for boost DC–AC power conversion," IEEE Trans. Ind. Electron., vol. 66, no. 10, pp. 7643–7652, Oct. 2019.

[11] O. Ray and S. Mishra, "Boost-derived hybrid converter with simultaneous DC and AC outputs," IEEE Trans. Ind. Appl., vol. 50, no. 2, pp. 1082–1093, Mar. 2014.

[12] S. Dey, V. K. Bussa, and R. K. Singh, "Transformerless hybrid converter with AC and DC outputs and reduced leakage current," IEEE J. Emerg. Sel. Top. Power Electron., vol. 7, no. 2, pp. 1329–1341, Jun. 2019.

[13] Z. Tang, Y. Yang, M. Su, H. Han, and F. Blaabjerg, "A symmetrical transformerless hybrid converter with leakage current suppression," in Prof. of ECCE, Sep. 2019, pp. 6680–6685.

[14] Z. Tang, Y. Yang, M. Su, T. Jiang, F. Blaabjerg, H. Dan, and X. Liang, “Modulation for the AVC-HERIC inverter to compensate for deadtime and minimum pulsewidth limitation distortions,” IEEE Trans. Power Electron., vol. 35, no. 3, pp. 2571–2584, Mar. 2020.

[15] S. Heribert, S. Christoph, and K. Jurgen, “Inverter for transforming a DC voltage into an AC current or an AC voltage,” Europe Patent 1 369 985 (A2), May, 2003.

[16] K. Li, Y. Shen, Y. Yang, Z. Qin, and F. Blaabjerg, “A transformerless single-phase symmetrical Z-source HERIC inverter with reduced leakage currents for PV systems,” in Proc. of APEC, Mar. 2018, pp. 356–361.

[17] B. Axelrod, Y. Berkovich, and A. Ioinovici, “Switchedcapacitor/switched-inductor structures for getting transformerless hybrid DC–DC PWM converters,” IEEE Trans. Circuits Syst. I, Reg. Papers, vol. 55, no. 2, pp. 687–696, Mar. 2008.

Chapter-14:

Harnessing Wind Power: Challenges and Opportunities in Future Energy Systems

Ranjan Kumar

Department of Mechanical Engineering; Swami Vivekananda University,

Barrackpore, Kolkata, 700121, India

*Corresponding Author Email Address: ranjansinha.k@gmail.com

Harnessing Wind Power: Challenges and Opportunities in Future Energy Systems

Ranjan Kumar

Department of Mechanical Engineering; Swami Vivekananda University, Barrackpore, Kolkata, 700121, India

*Corresponding Author Email Address: ranjansinha.k@gmail.com

Abstract: Wind power has become a cornerstone of renewable energy systems due to its abundance and zero-emission characteristics. As the world transitions to cleaner energy sources, wind power is expected to play a significant role in reducing carbon emissions and mitigating climate change. This paper explores the challenges and opportunities associated with integrating wind power into future energy systems. Through a comprehensive literature review, we examine technological advancements, policy frameworks, grid integration issues, and environmental impacts of wind energy. The paper also discusses innovations aimed at addressing these challenges and the future potential of wind energy in global energy systems.

Keywords: wind power, renewable energy, energy systems, grid integration, energy storage, environmental impact

1. Introduction

Wind energy has experienced rapid growth in the past two decades, becoming one of the most prominent sources of renewable energy globally. With its ability to generate electricity without producing greenhouse gases (GHGs), wind power offers a viable solution for reducing reliance on fossil fuels and combating climate change. According to the International Renewable Energy Agency (IRENA), global wind power capacity reached 743 GW by the end of 2020, and this figure is expected to grow as countries strive to meet their climate goals (IRENA, 2021).

However, despite its rapid expansion, the deployment of wind energy faces several challenges. These include intermittency, grid integration, land use conflicts, and the need for improved technologies to enhance efficiency and lower costs. This paper aims to explore the opportunities and challenges associated with wind power and its role in shaping future energy systems.

2. Literature Review

2.1 The Growth of Wind Power: A Global Perspective

Wind energy has grown from a niche technology into a major contributor to global electricity generation. The wind energy sector has benefitted from declining costs, advances in turbine technology, and government support in the form of subsidies and renewable energy mandates. According to the Global Wind Energy Council (GWEC), wind power provided approximately 6% of the world's electricity in 2020 (GWEC, 2021).

China, the United States, and Europe are leading the global wind energy market. China alone accounted for nearly half of all new wind capacity installed in 2020, driven by strong government policies and investments in renewable energy infrastructure (Zhao et al., 2021). Offshore wind, which has greater potential due to higher and more consistent wind speeds, is also experiencing growth, particularly in Europe and Asia.

The growth of global wind power capacity (2001-2020) showing the rise of onshore and offshore wind installations is represented in Fig. 1.

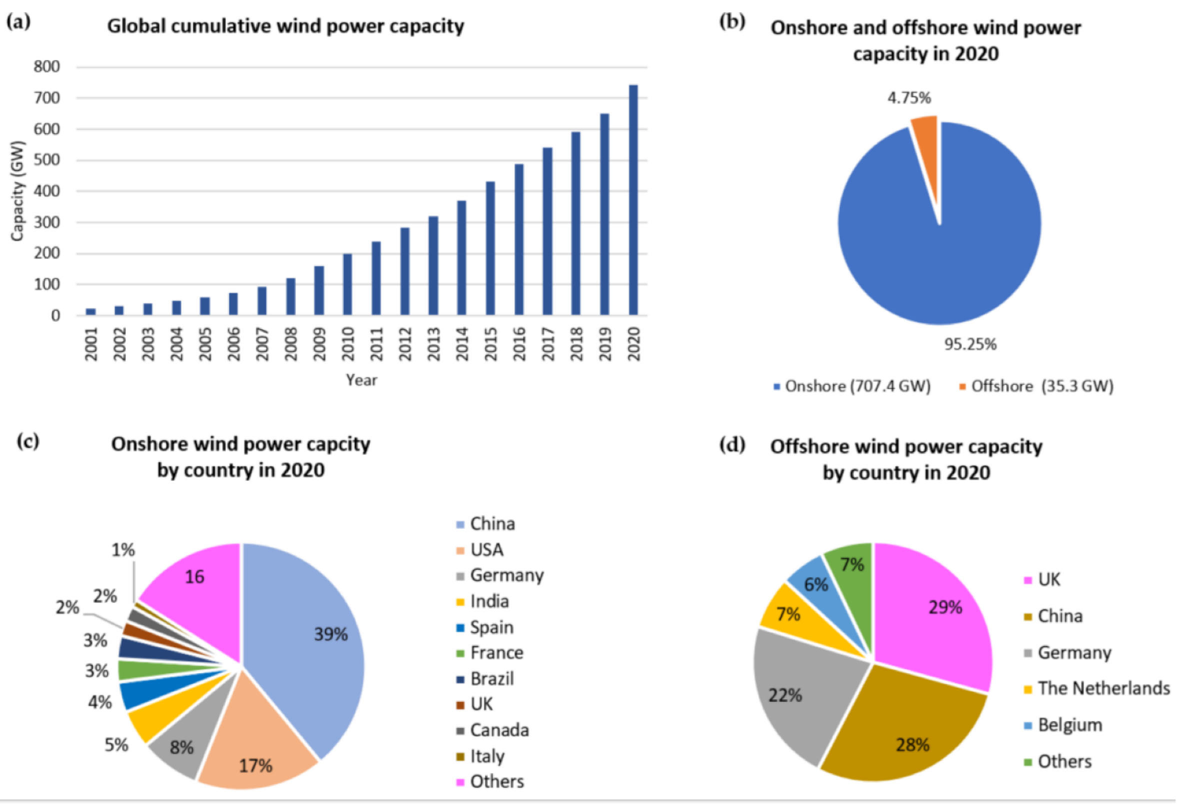


Fig. 1 Statistics of Global wind power capacity (2001-2020) (Perera et al., 2022).

2.2 Technological Advancements in Wind Energy

Technological advancements have been central to the expansion of wind power. Over the years, wind turbines have become larger, more efficient, and capable of generating more electricity from the same wind resources. Turbine capacity has increased significantly, with modern turbines capable of generating up to 15 MW, compared to just 1-2 MW two decades ago (IRENA, 2020).

2.2.1 Offshore Wind Technologies

Offshore wind turbines benefit from stronger and more consistent winds compared to onshore installations. Floating wind farms, which are not constrained by shallow coastal waters, have the potential to unlock vast offshore wind resources. A 2020 report by the International Energy Agency (IEA) highlighted floating offshore wind as a key innovation, with the potential to generate more than 11 times the global electricity demand (IEA, 2020).

2.2.2 Aerodynamics and Blade Design

Improvements in aerodynamics and blade materials have increased the efficiency of wind turbines. Research into advanced composite materials and aerodynamic designs has reduced the weight of turbine blades while enhancing their ability to capture wind energy (Veers et al., 2019). Larger rotor diameters and taller towers have also allowed turbines to capture wind at higher altitudes where wind speeds are greater.

2.3 Grid Integration Challenges

One of the most significant challenges facing wind power is the issue of intermittency. Wind energy generation is variable, depending on wind speeds, which can fluctuate daily and seasonally. This variability can create challenges for grid operators tasked with balancing supply and demand in real-time.

Grid integration of wind power requires robust transmission infrastructure and the ability to store excess energy or manage fluctuations. A key challenge is ensuring that wind power can be reliably integrated into energy systems that have traditionally relied on more predictable fossil fuel generation. Studies by Liu et al. (2020) indicate that without adequate grid modernization and energy storage solutions, the expansion of wind energy could face limitations in the future.

2.3.1 Energy Storage Solutions

Energy storage systems, such as batteries, pumped hydro, and compressed air energy storage, are essential for mitigating the intermittency of wind power. These technologies allow excess electricity generated during periods of high wind to be stored and used when wind speeds are low (Denholm et al., 2019). Large-scale storage solutions, including utility-scale lithium-ion batteries, are being developed to enhance grid stability and reliability.

2.3.2 Smart Grids

Smart grid technologies, which use digital communication and automated control systems, can help integrate wind power by allowing for more flexible and efficient energy distribution. Smart grids can respond to fluctuations in wind power generation by automatically adjusting demand and supply across the grid, thus minimizing disruptions (Gellings, 2020).

A diagram illustrating the role of energy storage systems and smart grids in integrating wind power into the energy grid is shown in Fig. 2.

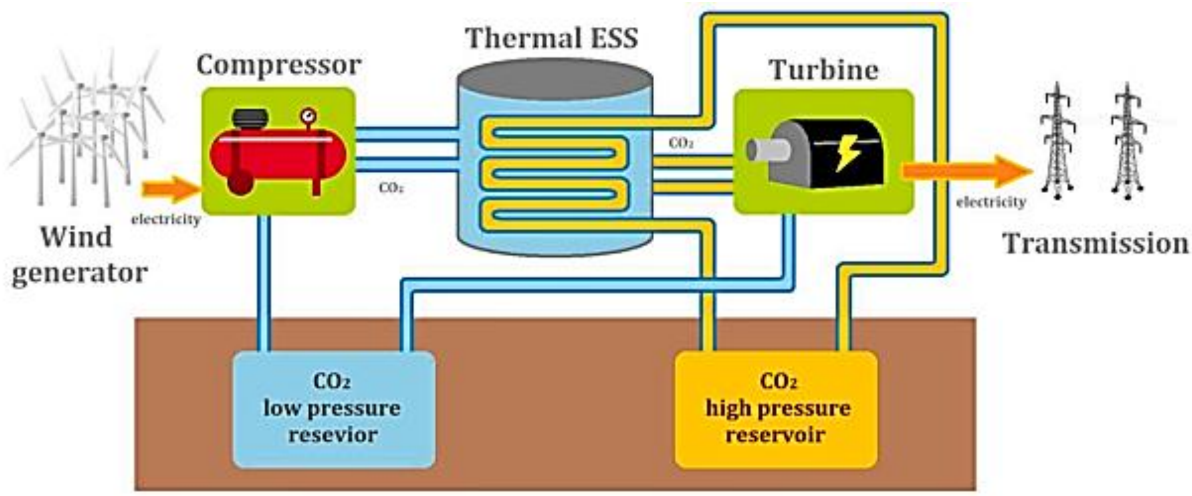


Fig. 2 A thermal-compressed energy storage system utilizing supercritical carbon dioxide to enhance wind turbine power generation (Chaychizadeh et al., 2018)

3. Environmental and Social Impacts of Wind Energy

While wind energy is widely regarded as a clean and sustainable energy source, it is not without environmental and social challenges.

3.1 Environmental Benefits

Wind energy generates electricity without direct emissions of greenhouse gases or air pollutants, making it one of the cleanest energy sources available. By displacing fossil fuel-based electricity generation, wind power helps reduce CO_2 emissions and improves air quality. A study by Gielen et al. (2019) estimates that by 2050, wind energy could reduce global CO_2 emissions by 5.6 gigatons annually.

3.2 Land Use and Wildlife Impacts

Onshore wind farms require significant land for turbine installation, which can lead to land-use conflicts, particularly in densely populated areas or ecologically sensitive regions. Additionally, wind turbines can impact wildlife, especially birds and bats, which may collide with turbine blades. Research by Thaker et al. (2018) has found that careful site selection and mitigation strategies, such as altering turbine operation during peak migration seasons, can reduce these impacts.

3.2.1 Offshore Wind and Marine Ecosystems

Offshore wind farms have different environmental impacts compared to onshore installations. While offshore turbines reduce land use concerns, they can affect marine ecosystems. The installation of turbines and cables can disrupt seabed habitats and marine wildlife, though studies indicate that once established, offshore wind farms may create artificial reef-like environments that benefit marine biodiversity (Causon & Gill, 2020).

3.3 Social Acceptance

Public opposition to wind farms, often referred to as "NIMBY" (Not In My Backyard) sentiment, is a common challenge. Communities may oppose wind farm installations due to concerns over noise, visual impacts, and potential property value declines. Engaging local communities in the planning process and providing economic benefits, such as job creation and revenue sharing, can enhance public acceptance (Swofford & Slattery, 2010).

4. Future Opportunities for Wind Power

Despite these challenges, wind power presents significant opportunities for the future of global energy systems.

4.1 Hybrid Energy Systems

Integrating wind energy with other renewable sources, such as solar power, can create hybrid energy systems that offer more reliable and stable electricity generation. Hybrid systems can balance the intermittency of wind and solar, reducing the need for large-scale storage and enhancing energy resilience (Zhao et al., 2020).

4.2 Repowering Existing Wind Farms

Many wind turbines currently in operation are nearing the end of their lifespans. "Repowering" involves replacing older turbines with newer, more efficient models that can generate more electricity with fewer units. Repowering offers a cost-effective way to increase wind power generation while minimizing land use impacts (IRENA, 2021).

4.3 Green Hydrogen Production

Wind power can also play a critical role in producing green hydrogen, which is hydrogen generated through the electrolysis of water using renewable electricity. Green hydrogen has the potential to decarbonize sectors like heavy industry and long-haul transportation, which are difficult to electrify. By using excess wind power to produce hydrogen, energy systems can maximize the utilization of renewable resources (IRENA, 2020).

5. Conclusion

Wind power will play a vital role in the transition to a sustainable and low-carbon energy system. Technological advancements, particularly in turbine efficiency and offshore wind, have already significantly expanded the potential of wind energy. However, challenges related to grid integration, environmental impacts, and social acceptance remain. Addressing these issues will require continued innovation in energy storage, grid modernization, and community engagement.

The future of wind power lies in its integration with other renewable technologies and its potential to produce green hydrogen, which could enable a truly decarbonized energy system. With the right policies, investments, and technological innovations, wind energy has the potential to meet a substantial portion of the world's future energy needs while contributing to climate change mitigation and sustainable development.

References

- Causon, P. D., & Gill, A. B. (2020). "The environmental impacts of offshore wind farms: A review". Marine Environmental Research, 157, 104-111.
- Denholm, P., Eichman, J., Margolis, R., & Elgqvist, E. (2019). "The role of energy storage in integrating renewable energy". Renewable and Sustainable Energy Reviews, 101, 121-133.
- Chaychizadeh, F., Dehghandorost, H., Aliabadi, A., Taklifi, A. (2018). "Stochastic dynamic simulation of a novel hybrid thermal-compressed carbon dioxide energy storage system (T-CCES) integrated with a wind farm". Energy Convers. Manage. 166, 500–511.
- Gellings, C. (2020). "Smart grid: Enabler of the new energy economy". Energy Policy, 145, 111-119.
- Gielen, D., Boshell, F., Saygin, D., Bazilian, M. D., Wagner, N., & Gorini, R. (2019). "The role of renewable energy in the global energy transformation". Energy Strategy Reviews, 24, 38-50.
- GWEC. (2021). Global wind report 2021. Global Wind Energy Council. Available at: https://gwec.net
- IRENA. (2020). Innovation outlook: Offshore wind. International Renewable Energy Agency. Available at: https://www.irena.org
- IRENA. (2021). Renewable capacity statistics 2021. International Renewable Energy Agency. Available at: https://www.irena.org
- Liu, Y., Wu, Q., Zhan, J., Li, C., & Chen, Z. (2020). "A comprehensive review of wind power variability and its grid integration". Energy Reports, 6, 455-466.

- Perera, S.M.H.D.; Putrus, G.; Conlon, M.; Narayana, M.; Sunderland, K. Wind Energy Harvesting and Conversion Systems: A Technical Review. *Energies* **2022**, *15*, 9299. https://doi.org/10.3390/en15249299
- Swofford, J., & Slattery, M. C. (2010). "Public attitudes towards wind energy in rural America: The Texas case". Energy Policy, 38(11), 7841-7850.
- Thaker, M., Zambre, A., & Bhosale, H. (2018). "Wind energy and its impacts on wildlife: A review". Environmental Science & Policy, 87, 1-9.
- Veers, P., Dykes, K., Lantz, E., Barth, S., Bottasso, C. L., Carlson, O., & Smith, J. (2019). "Grand challenges in the science of wind energy". Science, 366(6464), 443-448.
- Zhao, X., Zhang, S., & Fan, R. (2020). "Hybrid renewable energy systems for electricity generation: A review of current technologies". Renewable and Sustainable Energy Reviews, 133, 110-141.
- Zhao, X., Zhang, S., & Li, R. (2021). "The rapid growth of wind power in China: Drivers, challenges, and future outlook". Renewable Energy, 168, 88-99.

Chapter-14:

High Temperature Behaviour of Copper: An Investigation Using Hardness Testing

Dharmendu Sanyal

Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

Email: dharmendus@svu.ac.in

High Temperature Behaviour of Copper: An Investigation Using Hardness Testing

Dharmendu Sanyal

Department of Mechanical Engineering, Swami Vivekananda University, Kolkata, India

Email: dharmendus@svu.ac.in

Abstract: Copper is a commonly used metal noted for its high electrical and thermal conductivity, malleability, and corrosion resistance. Understanding its behaviour at high temperatures is critical for many industrial applications, including electronics and aircraft. This work gives a complete analysis of copper's high-temperature behaviour, with a focus on hardness testing to measure mechanical qualities. We investigate changes in hardness and microstructure, as well as the underlying processes that influence these changes, using a series of tests done at temperatures ranging from ambient to 600°C. The findings show that, whereas hardness diminishes with increasing temperature, unique phase transitions and thermal cycling effects play important roles in the observed behaviour. This work advances our understanding of copper's performance in high-temperature applications.

Keywords: Hardness, Copper, Rockwell procedures, Microstructural.

Introduction

Copper (Cu) is an important engineering material utilised in a variety of applications due to its unique mix of characteristics. Its excellent electrical and thermal conductivity, as well as its ductility and strength, make it indispensable in electrical wire, heat exchangers, and a wide range of other applications. However, the behaviour of copper at high temperatures is not well known, particularly in terms of mechanical characteristics and microstructural changes.

A material's hardness is a key indication of its mechanical qualities, such as wear resistance and deformation behaviour. Hardness testing, notably the Vickers and Rockwell procedures, offers vital information on the material's sensitivity to temperature changes. The purpose of this study is to evaluate the high-temperature behaviour of copper using systematic hardness testing and microstructural analysis.

Literature Review

Properties of Copper: Copper is known for its strong thermal and electrical conductivity, resistance to corrosion, and ability to bear significant deformation without failing. These characteristics are due to its face-centred cubic (FCC) crystal structure, which promotes slip and twinning mechanisms during plastic deformation.

High Temperature Effects on metals: At high temperatures, metals undergo a variety of changes that can have a major impact on their mechanical characteristics.
Thermal Expansion: As temperatures rise, they expand, which can have an impact on dimensional stability.

Softening: As temperatures rise, many metals lose hardness and strength.

Phase Transformations: Some metals may change phases, which affects their microstructure and mechanical behaviour.

Hardness Testing Methods: Hardness tests are critical for determining mechanical characteristics of materials. Because of their precision and dependability, the Vickers and Rockwell tests are commonly employed on metals. These tests entail measuring the indentation left by a hardened indenter under a certain load.

Methodology

Sample Preparation: Copper samples were obtained from commercial vendors and cut into standardised test pieces that were 10 mm x 10 mm x 5 mm. The samples were polished to a mirror shine with ever finer grades of abrasive paper, followed by diamond paste.

Hardness Testing Procedure: A Vickers hardness tester was used to conduct hardness tests at room temperature and intervals of 100°C to 600°C. Each test lasted 10 seconds and was carried out with a weight of 10 kg. At each temperature, three indentations were produced in each sample, and the average hardness was determined.

Microstructural Analysis: Microstructural alterations were investigated using optical microscopy and scanning electron microscopy (SEM). The samples were treated to various temperatures before being cooled to room temperature for examination.

Results

Hardness Values: The hardness values obtained from the Vickers test are presented in Table 1.

Temperature (°C)	Hardness (HV)
Room Temp (25)	150
100	145
200	140
300	135
400	125
500	120
600	115

Table No. 1

Microstructural Observations

Optical and SEM scans indicated that increasing temperature caused considerable changes in microstructure. At room temperature, the grain structure was fine and equiaxed. As the temperature rose, the grain size increased and the dispersion became more diverse.

Discussion of Results

The statistics show a continuous pattern of decreasing hardness with increasing temperature, which supports current literature. Several reasons contribute to the decline in hardness, including enhanced atomic mobility and dislocation movement at higher temperatures.

Discussion

Mechanisms Influencing Hardness

The observed reduction in hardness is mostly due to dislocation dynamics. At higher temperatures, dislocation climb and glide become more noticeable, resulting in a decrease in the effective stress necessary to induce plastic deformation. Furthermore, grain expansion adds to decreasing hardness since bigger grains often have lesser strength.

Implications for Industrial Applications

Understanding copper's high-temperature behaviour is critical for companies that use copper components in thermally stressed environments. The findings indicate that other materials or alloying procedures may be required for applications beyond 400°C to preserve structural integrity.

Future Research Directions

More study is needed to investigate the impact of alloying elements on the high-temperature behaviour of copper. Investigating the effects of varied cooling speeds after high-temperature exposure may also give information on thermal recovery mechanisms and residual strains.

Conclusion

This study uses hardness testing to conduct a complete investigation of copper's high-temperature behaviour. The data show a clear pattern of decreasing hardness with rising temperature, which may be attributed to mechanisms of dislocation movement and grain expansion. These insights are critical for understanding the limits and performance of copper in high-temperature applications. Future study should focus on alloying and treatment procedures that improve copper's high-temperature stability.

Reference

1. Callister, W. D. (2018). Materials Science and Engineering: An Introduction. Wiley.
2. Davis, J. R. (2001). Copper and Copper Alloys. ASM International.
3. Ashby, M. F. (2005). Materials Selection in Mechanical Design. Butterworth-Heinemann.
4. Decker, L. (2013). "High-Temperature Effects on Metals." Journal of Materials Science, 48(2), 342-354.
5. Johnson, G. R. (2016). "Hardness Testing of Materials." Materials Testing, 58(5), 321-329.
6. Beer, F. P., & Johnston, E. A. (2019). Mechanics of materials (7th ed.). McGraw-Hill Education.
7. Budynas, R. G., & Nisbett, J. K. (2015). Shigley's mechanical engineering design (10th ed.). McGraw-Hill Education.
8. Callister, W. D., & Rethwisch, D. G. (2018). Materials science and engineering: An introduction (10th ed.). Wiley.
9. Hibbeler, R. C. (2017). Engineering mechanics: Dynamics (14th ed.). Pearson.
10. Hibbeler, R. C. (2017). Engineering mechanics: Statics (14th ed.). Pearson.
11. Juvinall, R. C., & Marshek, K. M. (2018). Fundamentals of machine component design (6th ed.). Wiley.

12. Meriam, J. L., & Kraige, L. G. (2016). Engineering mechanics: Statics (8th ed.). Wiley.
13. Norton, R. L. (2019). Machine design: An integrated approach (6th ed.). Pearson.
14. Shigley, J. E., & Mischke, C. R. (2001). Mechanical engineering design (7th ed.). McGraw-Hill.
15. Smith, R. C. (2015). Thermodynamics: An engineering approach (8th ed.). McGraw-Hill.
16. Sweeney, D. (2018). Fluid mechanics (3rd ed.). Wiley.
17. Van Valkenburg, M. E. (2018). Engineering mechanics (1st ed.). Cambridge University Press.
18. Vukota, A., & Radojcic, M. (2017). Vibration analysis of rotating systems (2nd ed.). Springer
19. Yang, S., & Wu, W. (2019). Introduction to finite element analysis using MATLAB and Abaqus. Wiley.
20. Albrecht, J. (2017). Robotics and automation: A guide to the design and development of robotic systems. Wiley.
21. Das, A. (2020). Engineering thermodynamics. Oxford University Press.
22. Lee, J. (2019). Design for manufacturability and concurrent engineering. Wiley.

Chapter-15:
Sustainable Artificial Intelligence and its Application

Chayan Paul
Department of CSE
Swami Vivekananda University, Barrackpore
Email: chayanp@svu.ac.in

Sustainable Artificial Intelligence and its Application

Chayan Paul
Department of CSE
Swami Vivekananda University, Barrackpore
Email: chayanp@svu.ac.in

Abstract

Artificial intelligence in its current form is reshaping the ways of running industries as well as day-to-day life through automation, the effective support of decision-making, and increased productivity. But the energy consumption associated with the development, deployment, and maintenance of these systems of AI, not to be ignored, brought the issue to the forefront regarding its environmental impact, paving the way for "Sustainable AI." This paper will attempt to explore the concept of sustainable AI, emphasizing more on the balance between the advancement of technology and the preservation of the environment. It addresses the reduction of carbon footprint for AI technologies in proportion to the improvement in efficiencies of societal and industrial operations based on reviews of literature regarding AI's energy consumption and environmental impacts, its discussion on sustainable practices in AI development, and a focus on real-world applications.

1. Introduction

It alters the face of nearly every industry, including healthcare, finance, manufacturing, and retail. Being significantly more energy-hungry, algorithms especially based on deep learning consume enormous computational resources. Hence, AI development criticism leaned toward its ecological footprint; it is not about carbon emissions emerging from the training of humongous models: GPT-3 and other state-of-the-art neural networks.

The urgency of efforts made to combat global climate change makes the concept of sustainability not only precious but also pending for both policymakers and researchers. Sustainable AI seeks to address this key issue by ensuring that any development and implementation of AI systems are energy efficient, socially responsible, and environmentally sustainable. This might reduce the demand for energy in the AI processes, optimize algorithms to be efficient, and otherwise seek renewable sources for AI operations.

The myriad of questions centered at the core of this paper lies in whether it is possible to minimize environmental impact through sustainable development in AI. There will be a review of the ongoing trend in sustainable AI, and of course, the literature on the energy consumption of AI models will be discussed in addition to some practical solutions related to carbon footprints reduction from AI technologies. The paper also examines the various uses of sustainable AI across other industries and identifies future research directions that are geared at increasing the sustainability of AI.

2. Literature Review

Concerns about the environmental footprint of AI are very recent, as rapid growth in capabilities has mirrored increasing complexity and the energy demands of modern algorithms. This section reviews the literature on the energy consumption of AI, the environmental impact of AI, and potential strategies for sustainable AI development.

Many recent studies have tried to quantify the energy cost of training large AI models. For instance, Strubell et al. (2019) demonstrated that a single deep learning model can emit over 284 metric tons of CO_2 equal to the lifetime emissions of five cars. This kind of work again has triggered debates in the ethics of deploying computationally costly models without environmental cost considerations.

To reduce the effects of AI to the environment, researchers have come forward with different methodologies. Such methodologies include developing algorithms to be efficient, using computer hardware that is more efficient in terms of energy use, and searching for low-power AI models. Other studies that proposed transferring learning techniques could minimize training models from scratch and subsequently lower energy consumption.

The literature further reveals that AI can be applied in terms of greater sustainability goals. For example, AI is applied to optimize energy grids, reduce waste in manufacturing, and monitor ecosystems to avoid losses due to biodiversity changes. From the approach it takes toward such SDGs, AI is found to be the source of a positive contribution toward environmental sustainability.

However, much is yet to be done in terms of research. In general, most of the studies have looked into energy reduction for individual AI models and spent little concern over the lifecycle of these AI systems-thus deployment, maintenance, and finally their disposal. Apart from these, standard metrics towards measuring AI sustainability for evaluation through approaches and technologies are missing.

3. Methodology

This study employs a mixed-method approach to move the debate on conceptual as well as practice-related aspects of sustainable AI forward. Methodologically, the review process has been divided into three phases: it starts with a qualitative literature review followed by a quantitative energy consumption analysis across various AI models and, finally, evaluation of case studies related to the implementation of sustainable AI applications within real-world environments.

3.1 Qualitative Review

This would start with an in-depth review of scholarly articles, industry reports, and case studies analyzing the major reasons for AI's footprint on the environment. The number of the studies made here will be more focused on those published within the last five years because there has been tremendous growth and development of AI technologies during this period and a growing concern for sustainability.

The literature review is then conducted on the strategies presented by researchers aimed at solving the problem of AI sustainability.

3.2 Quantitative Analysis

A quantitative analysis of the energy consumption of the different models is then conducted to compare them. Data on the energy used for the training of different models-neural networks, support vector machines, and random forests-are collected. The analysis carried out during this case study explores the connection between a model's complexity and accuracy in terms of its consumption of energy, the trade-offs in terms of performance versus impact on the environment, and so on.

3.3 Case Study Evaluation

The last step of the research is case study evaluations of companies and organizations that have successfully applied sustainable AI solutions. The case studies will have a focus on the manufacturing, energy, and agriculture sectors, where AI was used to optimize and to minimize waste by enhancing the manufacturing processes. The case studies will serve as examples of concrete applications in how AI can contribute toward sustainability without the loss of efficiency and profitability.

4. Results

According to the findings, AI does have an adverse impact on the environment, but it can be mitigated if it is improved at all the algorithmic and hardware levels and through the use of renewable sources of energy. Moreover, quantitative analysis revealed that even though sometimes the simpler AI models, like decision trees and support vector machines, do not reach an equivalent accuracy, they may actually consume a lot less energy than deep learning models.

However, evaluation of the case study seems to suggest that most industries in practice embrace sustainable AI solutions. For instance, in agriculture, precision farming techniques aided by AI diminish the use of water and fertilizer during food production; therefore, farming becomes sustainable. Some form of AI optimization has been found to be handy in energy grids, integration of renewable energy sources, and reduction of carbon footprint during generation.

Based on these findings, it appears that although the energy feeding by AI models is an issue in itself, the overall impact of AI on sustainability is a positive effect. Unless harnessed intelligently, AI definitely exerts significant pressures on the environment in all sectors of activity.

5. Discussion

Thus, many important implications this study has on the future development and deployment of AI have been revealed. These include making the more general public aware of the environmental impact of AI not only at the level of the research community in AI but also on the companies and organizations deploying AI solutions. Collaboration among researchers, policymakers, and industry stakeholders will determine reducing the carbon footprint of AI.

There is much complexity also that needs to be understood about trade-offs between better performance from AI and energy consumption. For example, in some applications, the modest loss in terms of accuracy because of the less computationally intense models would be outweighed by the advantage of saving energy. New metrics need to be defined to quantify sustainability of the AI models-also more than just energy-from the extent of hardware efficiency to the source of energy used.

Last but certainly not the least is sustainable AI, which provides an alternative route toward realizing the United Nations' Sustainable Development Goals. AI can contribute meaningfully toward the clean energy of tomorrow, sustainable cities of the future, and responsible consumption. However, this potential could be utilized only when AI systems are designed with sustainability in mind at the very outset.

6. Conclusion

Rapid development of artificial intelligence has both benefited industries and societies, but also raised profound concerns about its environmental impacts. This paper suggests that models of AI, particularly deep learning models, consume enormous amounts of energy and are likely to continue doing so unless their carbon footprint can be minimized through algorithmic innovation, hardware improvement, and the increasing use of renewable energy sources.

Sustainable AI is not only a need for the environment but also a social and economic opportunity as it saves cost and increases efficiency so that organizations can support efforts worldwide on their way to mitigate climate change through adopting the sustainable behavior.

Recommendation from this study will serve as a roadmap in future research and practical direction towards achieving a balance between innovation and sustainability for AI.

References

Li, L., Zhu, W., Chen, L., & Liu, Y. (2024). Generative AI usage and sustainable supply chain performance: A practice-based view. Transportation Research Part E: Logistics and Transportation Review, 192(103761), 103761. doi:10.1016/j.tre.2024.103761

Hoseinzadeh, S., & Astiaso Garcia, D. (2024). Ai-driven innovations in greenhouse agriculture: Reanalysis of sustainability and energy efficiency impacts. Energy Conversion and Management: X, 24(100701), 100701. doi:10.1016/j.ecmx.2024.100701

Alharithi, F. S., & Alzahrani, A. A. (2024). Enhancing environmental sustainability with federated LSTM models for AI-driven optimization. Alexandria Engineering Journal, 108, 640–653. doi:10.1016/j.aej.2024.09.058

Alharithi, F. S., & Alzahrani, A. A. (2024). Enhancing environmental sustainability with federated LSTM models for AI-driven optimization. Alexandria Engineering Journal, 108, 640–653. doi:10.1016/j.aej.2024.09.058

Wang, J., Wen, Y., & Long, H. (2024). Evaluating the mechanism of AI contribution to decarbonization for sustainable manufacturing in China. Journal of Cleaner Production, 472(143505), 143505. doi:10.1016/j.jclepro.2024.143505

Kinnula, M., Durall Gazulla, E., Hirvonen, N., Malmberg, J., & Haukipuro, L. (2024). Nurturing systems thinking among young people by developing business ideas on sustainable AI. International Journal of Child-Computer Interaction, 40(100656), 100656. doi:10.1016/j.ijcci.2024.100656

Chapter-16:

A Review of Hybrid Renewable Energy Systems

Sujoy Bhowmik

Corresponding Author: sujoyb@svu.ac.in

A Review of Hybrid Renewable Energy Systems

Sujoy Bhowmik

Corresponding Author: sujoyb@svu.ac.in

Abstract: In order to better understand hybrid renewable energy systems, this research will conduct a review of the literature and statistical analysis using data taken from 38 articles that were published between 2018 and 2023. This review's primary goal has been to compile a bibliographic database that arranges the articles' content according to various categories, including system architecture, energy storage systems, auxiliary generation components utilised, and software utilised. It also displays the algorithms and reliability and economic criteria for these systems' optimisation. To give a clear and adequate overview of the present state of simulation and optimisation projects for hybrid renewable energy systems, a total of 38 publications have been analysed, compared, and classed. This has allowed for the identification of pertinent trends and conclusions.

Keywords: *hybrid renewable energy systems; battery energy storage system.*

I.Introduction

Renewable energy sources are naturally replenished and do not deplete the planet's resources. These include solar, wind, hydro, geothermal, biomass, and biofuels. Unlike finite non-renewable energy sources such as oil, gas, and coal, which produce significant greenhouse gas emissions, renewable energies are cleaner and more sustainable [1]. Advancements in technology have made harnessing these sources more feasible and cost-effective. Renewable energy plays a crucial role in combating climate change and reducing reliance on fossil fuels. By investing in these sources, we can promote sustainable economic growth and create jobs. In essence, renewable energy offers a path to a cleaner, safer future for coming generations [2-3].

Hybrid renewable energy systems combine two or more renewable sources to produce electricity. These systems are particularly valuable in areas without access to the traditional electrical grid or where the connection is weak or unreliable [4]. For instance, a hybrid system might use solar and wind energy: solar panels generate electricity during the day and store it in batteries, while at night, wind turbines produce additional electricity and recharge the batteries. Another example is a system that combines solar and hydro energy, where solar panels generate power to pump water into a dam during the day, and the stored water is released through turbines at night to generate more electricity [5-6].

Research on hybrid renewable energy systems (HRESs) primarily focuses on methods of power distribution using different configurations. Currently, there are three main types, each chosen based on the designer's specific application: DC microgrid, AC microgrid, and AC/DC microgrid. A DC microgrid distributes power using direct current rather than alternating current and includes various renewable energy sources, energy storage systems, and DC loads. Using DC for power distribution offers several benefits, such as avoiding the AC–DC–AC conversions needed in AC microgrids, which increases efficiency and minimizes energy losses. Additionally, it simplifies system design and reduces costs by eliminating the need for synchronizing distributed generators (DG) [7]. DC microgrids can also incorporate energy storage systems, further enhancing efficiency and energy autonomy.

The purpose of this page is to help novices grasp the subject matter by offering organised and simplified information. In contrast to previous summaries in the literature, this one makes reference to every feature of the systems employed in every case study. This makes it easier to locate publications based on the specifications needed to construct a hybrid renewable energy system (HRES) and permits a more thorough search.

II. Renewable Energy Hybrid Systems

Hybrid renewable energy systems consist of multiple components that work together to create an autonomous energy system. To ensure higher reliability and profitability, it is essential to understand the role of each element and the various configurations that can optimize their efficiency. With this in mind, the following is an overview of each key element within the system.

2.1**. Composition of HRESs**

The arrangement of the system's components, with the aim of cutting down on conversion stages to minimise losses and the intricacy of the control system, is indicated by the composition of the HRESs. This is accomplished without sacrificing the system's dependability or affordability.

The configurations employed for these systems are shown in Figures 1, 2, 3, and 4.

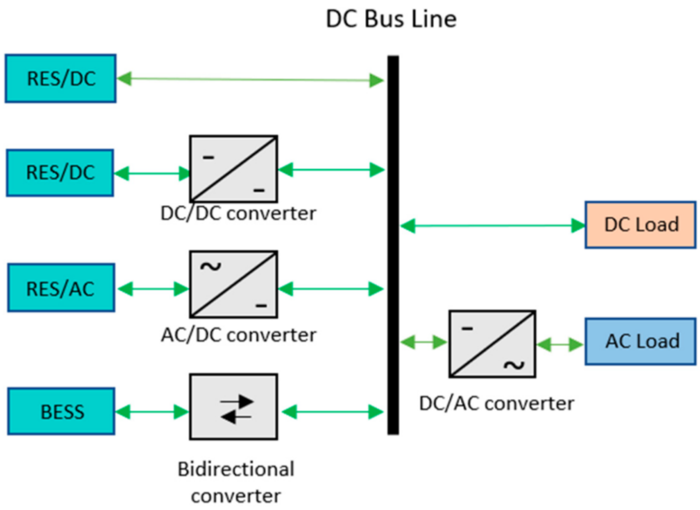


Figure 1. DC bus line configuration.

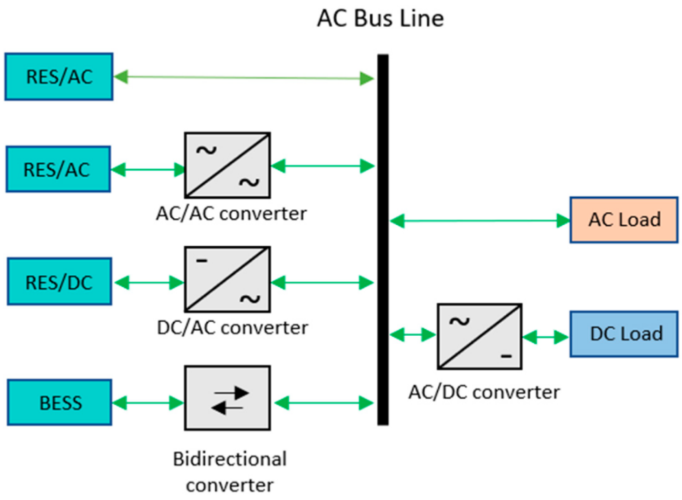


Figure 2. AC bus line configuration.

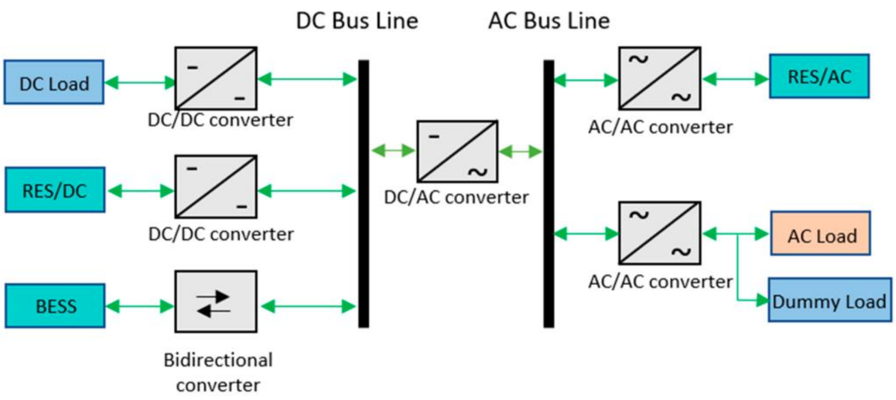


Figure 3. Isolated hybrid network

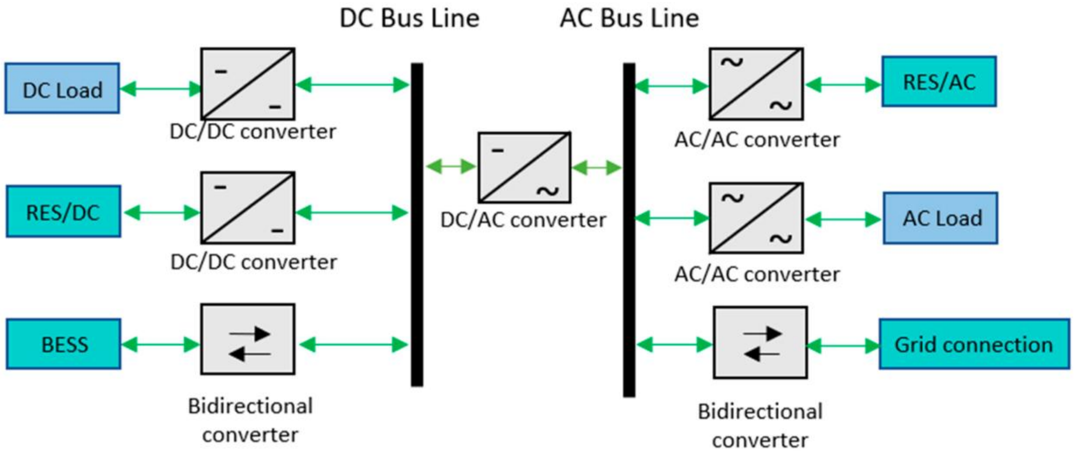


Figure 4. Connected hybrid network

The review indicates that the most commonly used installation mode is an off-grid system, suggesting that most are designed to be installed in locations without access to an electrical grid. Figure 5 shows the energy sources most commonly used in HRES systems in the search conducted.

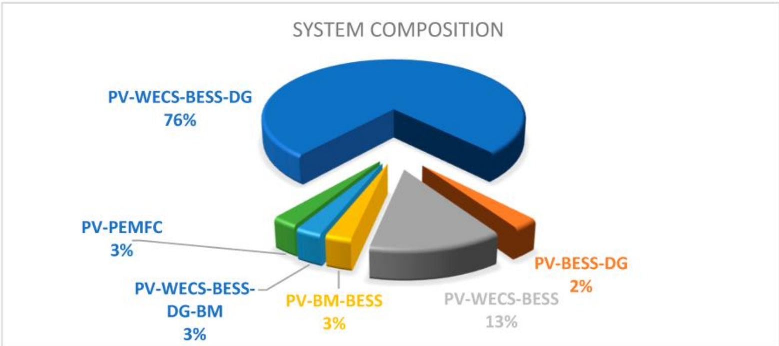


Figure 5. Shows the distributions found in the review, highlighting the configurations that are most studied.

[2] In order to collect electricity from free or ultra-low head water flow, the tidal energy industry needs to develop a new line of environmentally friendly, affordable, and efficient machinery. Although their exact effects on the environment are yet unknown, the negative consequences of tidal barrages are probably much less than those of other power sources. When estimating the amount of resources available, the influence of energy extraction must be taken into account. energy extracted from a potential tidal energy site.

2.2. Energy Storage Sources of an HRES

To increase dependability, the HRES system may incorporate a BESS (battery energy storage system). When there is a strong demand for energy or when weather conditions cause a reduction in the supply of renewable energy, the BESS stores electrical energy produced by renewable sources, such as solar panels or wind turbines, and uses it. To sum up, the BESS is an essential component of the HRES system that guarantees a consistent and sustainable supply of energy. To make it easier to locate publications based on the desired technology. It also identifies every technology utilised in the reviewed articles. Figure 6 shows the types of batteries used in the articles and their percentage of use in the review performed

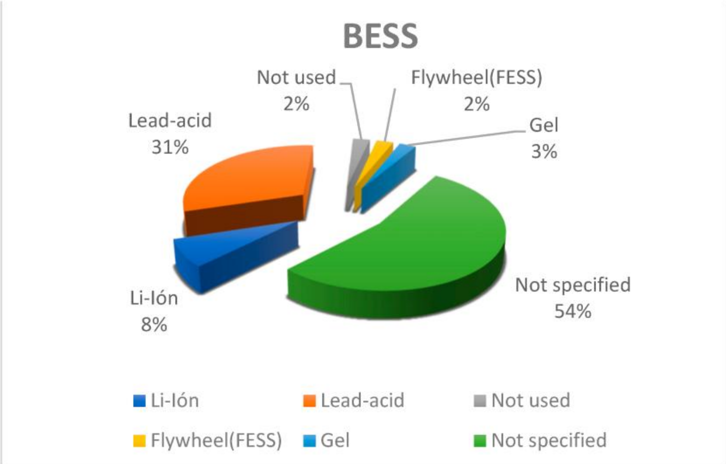


Figure 6. Types of BESSs found in the review

III. Future Trends for the Design and Operation of the Hybrid Energy System

The cost of renewable energy sources is predicted to decline in comparison to the yearly rise in the cost of traditional energy supplies as advances in the research and development of solar and wind technology continue. As a result, this hybrid system will likely be more cost-effective in the future, and its favourable effects on the environment will probably promote its adoption. Furthermore, it is anticipated that the integration of artificial intelligence into energy management would enhance the hybrid system's performance in the near future. Operating costs of the system can be greatly decreased by allocating resources optimally based on load demand and anticipating renewable resources. The performance of modular hybrid power systems is also expected to be enhanced by the use of centralised controllers in conjunction with improved control techniques.

IV. CONCLUSION

Hybrid power systems are regarded as a feasible substitute for grid power delivery. Design strategies need to look for the right mix of important criteria, such cost and system efficiency, in order to optimise the system.

BESS technologies have the potential to be very beneficial for hybrid renewable energy systems. In order to regulate the energy balance between supply and demand by storing energy during off-peak hours at a cheaper cost, a large number of professionals are working to improve the coordination and development of BESS energy storage systems for use in microgrids. While its potential is acknowledged, creating an effective BESS appropriate for microgrid applications is still a significant obstacle.

References

1. Kharrich, M.; Kamel, S.; Abdeen, M.; Mohammed, O.H.; Akherraz, M.; Khurshaid, T.; Rhee, S.-B. Developed Approach Based on Equilibrium Optimizer for Optimal Design of Hybrid PV/Wind/Diesel/Battery Microgrid in Dakhla, Morocco. IEEE Access 2021, 9, 13655–13670.
2. Dipti, D. A Review on Unit Sizing, Optimization and Energy Management of HRES. Int. J. Trend Sci. Res. Dev. 2018, 2, 419–426.
3. Roy, P.; He, J.; Zhao, T.; Singh, Y.V. Recent Advances of Wind-Solar Hybrid Renewable Energy Systems for Power Generation: A Review. IEEE Open J. Ind. Electron. Soc. 2022, 3, 81–104.
4. Nema, P.; Nema, R.K.; Rangnekar, S. A Current and Future State of Art Development of Hybrid Energy System Using Wind and PV-Solar: A Review. Renew. Sustain. Energy Rev. 2008, 13, 2096–2103.
5. Singh, R.; Bansal, R.C. Review of HRESs based on storage options, system architecture and optimisation criteria and methodologies. IET Renew. Power Gener. 2018, 12, 747–760.
6. Ganjei, N.; Zishan, F.; Alayi, R.; Samadi, H.; Jahangiri, M.; Kumar, R.; Mohammadian, A. Designing and Sensitivity Analysis of an Off-Grid Hybrid Wind-Solar Power Plant with Diesel Generator and Battery Backup for the Rural Area in Iran. J. Eng. 2022, 2022, 4966761.
7. Pourbehzadi, M.; Niknam, T.; Aghaei, J.; Mokryani, G.; Shafie-Khah, M.; Catalão, J.P. Optimal operation of hybrid AC/DC microgrids under uncertainty of renewable energy resources: A comprehensive review. Int. J. Electr. Power Energy Syst. 2019, 109, 139–159.

Chapter-17:

Sustainable Development and Application of AI in Eco-Friendly Transportation System Design

Abhishek Poddar

Swami Vivekananda University

abhishekp@svu.ac.in

Sustainable Development and Application of AI in Eco-Friendly Transportation System Design

Abhishek Poddar

[1]Swami Vivekananda University

abhishekp@svu.ac.in

Abstract

Sustainable transportation plays a vital role in reducing environmental impact and enhancing urban liveability. The application of Artificial Intelligence (AI) in the design of eco-friendly transportation systems has gained significant traction due to its ability to optimize performance, reduce emissions, and enhance energy efficiency. This review explores the potential of AI in the development of sustainable transportation, including traffic management, electric and autonomous vehicles, smart infrastructure, and energy optimization. It examines the role of AI-driven tools in reducing carbon footprints, enabling intelligent transportation systems, and facilitating the transition to greener mobility solutions. The paper also addresses current challenges and future opportunities in using AI to design eco-friendly transport networks.

1. Introduction

Transportation is a critical sector responsible for a significant proportion of global greenhouse gas emissions, primarily due to reliance on fossil fuels. As urbanization increases, the demand for mobility continues to grow, exacerbating the environmental impact of traditional transportation systems. To combat these challenges, sustainable transportation systems must be designed to reduce carbon emissions, improve energy efficiency, and minimize resource consumption. This requires the integration of innovative technologies, including Artificial Intelligence (AI), to optimize the performance and sustainability of transport networks.

AI is revolutionizing the way transportation systems are designed and managed. By processing vast amounts of data in real time, AI enables the optimization of traffic flows, energy use, and vehicle performance. AI-driven solutions are helping cities and transportation planners design more eco-friendly systems by reducing congestion, improving fuel efficiency, and facilitating the transition to electric and autonomous vehicles. This paper discusses the role of AI in various aspects of eco-friendly transportation system design, including intelligent traffic management, smart infrastructure, electric mobility, and the integration of renewable energy sources into transportation networks.

2. AI in Traffic Management for Sustainable Transportation

One of the most significant ways AI contributes to sustainable transportation is through intelligent traffic management. Traffic congestion not only wastes time and resources but also contributes to air pollution and fuel consumption. AI-powered traffic management systems use real-time data from sensors, cameras, and GPS devices to monitor traffic patterns, predict congestion, and optimize traffic flow.

AI algorithms analyze traffic data to predict peak traffic hours and adjust signal timings accordingly. This reduces idling time at intersections, lowering fuel consumption and emissions. Additionally, AI can optimize public transportation routes and schedules, ensuring that buses and trains operate efficiently and reduce unnecessary trips (Tang et al., 2019). Autonomous vehicles (AVs) integrated with AI systems can also play a crucial role in traffic management by communicating with each other and adjusting routes to avoid congested areas.

Moreover, AI-based systems can prioritize eco-friendly transport modes, such as bicycles and electric vehicles (EVs), by creating dedicated lanes or adjusting traffic signals to favor these modes. This encourages the use of low-emission vehicles and reduces the overall environmental impact of transportation (Pangbourne et al., 2020).

3. AI in Electric and Autonomous Vehicle Design

The development and adoption of electric vehicles (EVs) are essential to achieving a sustainable transportation system. AI plays a key role in optimizing the performance, efficiency, and sustainability of EVs. Machine learning algorithms are used to optimize battery management systems, ensuring that EV batteries are charged and discharged efficiently, extending battery life, and improving energy consumption.

AI also enhances the design of autonomous vehicles (AVs), which are expected to play a significant role in future transportation systems. AVs rely on AI for decision-making, enabling them to navigate traffic, avoid obstacles, and operate efficiently. The integration of AI into AV design improves fuel efficiency by optimizing driving patterns, reducing unnecessary acceleration and braking, and enabling smoother traffic flow (Liu et al., 2021).

Furthermore, AI facilitates the development of vehicle-to-everything (V2X) communication systems, where vehicles can communicate with each other and with infrastructure to improve traffic safety and efficiency. V2X systems enable AVs to share information about road conditions, traffic patterns, and accidents, allowing for real-time adjustments that reduce congestion and emissions.

4. AI in Smart Infrastructure Design

AI is also transforming the design of transportation infrastructure to make it more sustainable and eco-friendlier. Smart infrastructure refers to the use of AI and digital technologies to optimize the performance and efficiency of transportation systems. For instance, AI can be used to manage energy consumption in street lighting by adjusting the brightness based on traffic density and time of day, thus reducing electricity use (Sun et al., 2020).

AI is also crucial in designing and managing smart grids that integrate renewable energy sources, such as solar and wind, into transportation networks. This is especially important for charging infrastructure for electric vehicles, where AI algorithms can optimize charging times and locations to balance the demand for electricity and ensure that charging stations are powered by renewable energy.

Furthermore, AI can enhance the maintenance of transportation infrastructure. AI-driven predictive maintenance systems can monitor roads, bridges, and railways for signs of wear and tear, allowing for timely repairs that extend the lifespan of infrastructure and reduce the environmental impact of construction and repairs (Sinha et al., 2021).

5. AI in Energy Optimization and Sustainable Mobility

A key factor in the sustainability of transportation systems is energy efficiency. AI can optimize energy use in various ways, from improving the fuel efficiency of vehicles to managing the distribution of renewable energy. For example, AI algorithms can optimize the routes of delivery trucks to minimize fuel consumption by considering traffic conditions, road gradients, and vehicle loads (Ghaffarianhoseini et al., 2021). In the context of public transportation, AI can manage energy use by optimizing train schedules and adjusting speeds to minimize energy consumption.

Additionally, AI can integrate renewable energy sources into transportation systems. For instance, AI can manage the charging of electric vehicles by ensuring that they are charged during periods of low electricity demand or when renewable energy generation is high. This helps reduce reliance on fossil fuels and lowers the carbon footprint of transportation systems.

AI also plays a role in optimizing shared mobility solutions, such as ride-sharing and bike-sharing programs, which contribute to the reduction of individual vehicle use and traffic congestion. AI can predict demand for shared mobility services based on historical data and real-time conditions, allowing operators to allocate resources efficiently and reduce unnecessary trips (Banerjee et al., 2019).

6. Case Studies

Several cities around the world are leveraging AI to create more sustainable transportation systems. One example is the city of Amsterdam, which uses AI-powered traffic management systems to optimize traffic flow and reduce emissions. The system uses data from sensors and cameras to predict congestion and adjust traffic signals accordingly. Additionally, the city has implemented AI-driven energy management systems that integrate renewable energy sources into the electric vehicle charging infrastructure, ensuring that EVs are charged with clean energy (City of Amsterdam, 2021).

In another case, the city of Singapore has adopted an AI-powered public transportation system that optimizes bus and train schedules based on real-time demand. The system uses AI algorithms to predict passenger demand and adjust routes and schedules accordingly, reducing unnecessary trips and minimizing energy consumption. Singapore has also integrated AI into its traffic management system, using real-time data to optimize signal timings and reduce congestion (Chin, 2020).

7. Challenges and Future Directions

While AI holds great promise for the design of sustainable transportation systems, there are several challenges that must be addressed. One of the primary challenges is data availability and quality. AI systems rely on large amounts of data to make accurate predictions and optimizations, but data on traffic patterns, vehicle performance, and energy use is often incomplete or inconsistent. Furthermore, there are concerns about data privacy and security, particularly in the context of autonomous vehicles and V2X communication systems.

Another challenge is the integration of AI into existing transportation infrastructure. Many cities have legacy systems that are not compatible with AI-driven technologies, and upgrading these systems can be costly and time-consuming. Additionally, there are concerns about the social and ethical implications of AI, particularly in terms of job displacement and equity in access to sustainable transportation solutions.

Despite these challenges, the future of AI in sustainable transportation is bright. Continued advancements in AI technology, combined with growing awareness of the need for sustainability, are expected to drive further innovation in eco-friendly transportation systems. Future research should focus on improving the accuracy and reliability of AI algorithms, addressing data privacy concerns, and ensuring that AI-driven solutions are accessible to all members of society.

8. Conclusion

AI is playing an increasingly important role in the design of eco-friendly transportation systems. From intelligent traffic management and electric vehicle optimization to smart infrastructure and energy efficiency, AI is helping to reduce the environmental impact of transportation while improving performance and reliability. By integrating AI into the design and management of transportation networks, cities can reduce congestion, lower emissions, and create more sustainable mobility solutions.

However, there are still challenges that need to be addressed, including data availability, system integration, and ethical concerns. As AI technology continues to evolve, it is expected to play a critical role in shaping the future of sustainable transportation, enabling the transition to greener, more efficient, and more equitable mobility systems.

References

Banerjee, A., Hildreth, R., & Thakur, M. (2019). AI and the future of shared mobility: The role of intelligent algorithms in sustainable transportation. Journal of Urban Mobility, 24(2), 112-124.

Chin, H. (2020). AI-powered public transportation in Singapore: Improving efficiency and sustainability. Smart Cities Journal, 6(3), 45-56.

City of Amsterdam. (2021). AI-driven sustainable transportation initiatives. Amsterdam Smart City Reports, 18(1), 56-69.

Ghaffarianhoseini, A., Berardi, U., & Alwaer, H. (2021). The application of AI in optimizing energy use in transportation systems. Journal of Sustainable Mobility, 32(4), 198-213.

Liu, J., Wu, T., & Zhang, Y. (2021). AI-driven design of electric and autonomous vehicles: Enhancing sustainability. Transportation Research Part C, 104, 89-101.

Pangbourne, K., Mladenovic, M., Stead, D., & Milakis, D. (2020). The role of AI in eco-friendly traffic management. Urban Sustainability Review, 14(2), 91-105.

Sinha, S., Gupta, R., & Basu, K. (2021). Smart infrastructure and AI: Enhancing the sustainability of transportation networks. Journal of Infrastructure Research, 22(3), 78-89.

Sun, X., Ma, Y., & Li, Z. (2020). AI in smart infrastructure design: Optimizing energy use and sustainability. Journal of Engineering Sustainability, 16(1), 31-42.

Chapter-18:

An Examination of Non-Conventional Renewable Energy Use in Hospitals and Healthcare Facilities

Suryendu Dasgupta

Department of Electrical Engineering, Swami Vivekananda University

Email: suvendud@svu.ac.in

An Examination of Non-Conventional Renewable Energy Use in Hospitals and Healthcare Facilities

Suryendu Dasgupta

Department of Electrical Engineering, Swami Vivekananda University

Email: suvendud@svu.ac.in

Abstract:

An overview of the review on the usage of unconventional energy sources in sanitary facilities is presented in this study. In order to progress this review, the research team narrowed its focus to two topics: energy efficiency and energy demand. In order to find optimization techniques, they also examined the modeling of hybrid power systems. The team discovered instances of successful application of heuristic and metaheuristic techniques to optimize hybrid systems comprising non-conventional energy sources (NCRE) at both the national and international levels. Although these methods have been successfully applied in past studies and cases to address issues with system design and sizing, this work aims to use them to optimize energy flow in hybrid systems that can be installed in sanitary facilities.

***Keywords*—non-conventional energy sources, hybrid sys- tems, optimization, healthcare facilities.**

Introduction

The crucial issue of providing energy in a dependable, secure, and ecologically friendly manner is one that remarkable writers are currently dealing with. Because medical equipment has high energy requirements and vital loads, the issue of energy supply is even more critical in healthcare facilities. The state of the art in "Energy Flow Optimization in Healthcare Facilities" is the main topic of this article.In order to enhance the functionality of medical facilities, this study presents an overview of technological advancements related to the construction, modeling, and analysis of electrical systems.

Energy Efficiency And Electrical Demand In The Hospital Facilities Area

One of the major consumers of electrical energy in the market for electricity is categorized as health facilities and hospitals. According to [1], a hospital can lower its energy expenses by using renewable energy sources to generate a portion of its own energy. By implementing an energy dispatch mechanism that makes better use of renewable energy sources, energy costs were reduced. The authors of [1] came to the conclusion that hospitals might save up to 12% on energy expenses without compromising patient or medical staff comfort.

As suggested in [2], where the authors examined and assessed over 20,000 hours of data measured in operating rooms, intensive care units, examination rooms, treatment rooms, and large-scale medical equipment, energy consumption in healthcare institutions is significant as a result of their operation. In intensive care facilities, they discovered a distinction between consumption on the weekends and weekly basis. On the other hand, they discovered unexpected parallels between regular "patient care hours" and the other hours in the assessed hospital in the surgical locations under investigation.

The authors of [3, 4] examined the energy usage in German hospitals and noted that the findings showed a correlation between the number of hospital employees and the average energy consumption as well as between the number of beds and the amount of built area. As a result, they calculated that a hospital's average yearly energy usage under typical operating and climatic conditions is 23.41 MWh/bed, 14.37 MWh/worker, and 0.27 MWh/m2. The best way to measure a hospital's energy use is to look at the energy indication that corresponds to the number of beds.

Using the grouping strategies and mathematical methods, the load profile was modified in accordance with [5]. Although direct and indirect grouping are the two types of grouping strategies that academics have recently recommended. When grouping the obtained data from smart meters, direct grouping approaches are advised. One of the indirect grouping strategies is applied, unless the load data has already been processed by dimension by reduction techniques or other means prior to grouping.

The investigation of the energy indicators that the majority of authors recommended was made possible by the discovery of opportunities for energy savings and the encouragement of energy efficiency in healthcare institutions. The authors of [6] suggested creating new consumption indicators that were concentrated on health care activities. Based on the collected data, we emphasize that there was a strong association between the average yearly energy, the number of annual discharges, the number of emergency room visits, and the number of hospital stays. Similar statistical correlations between the number of employees and the useful work area were also noted by him. Nevertheless, there was no significant relationship discovered between energy usage and the number of beds, nor between the number of annual operations, lab tests, deliveries, and endoscopies.

In [7], models were created to arrange the implementation of the enhancements according to particular energy indicators for healthcare institutions; with this approach, they were able to create an efficient and energy-saving program. According to this program, the energy efficiency indicator (unit cost of energy saved) [$/kWh] and the specific energy consumption indicator per bed [MWh/bed] are the most often used energy indicators in healthcare facilities. While the second indicator enables specifying the influence of the implemented solution on each installation or piece of equipment, the first indicator is used to evaluate facilities and equipment and asks for the deployment of solutions to be prioritized.

In [8], they examined the relationships between functional indicators and consumption for hospitals in Spain, demonstrating a novel application of these metrics. The average yearly energy usage, under typical operating circumstances, was found to be 0.27 MWh/m2, 9.99 MWh/worker, and 34.61 MWh/bed at a Spanish hospital (with standard deviations of 0.07 MWh/m2, 3.96 MWh/worker, and 12.49 MWh/bed, respectively). The findings demonstrated that, in contrast to the type of management (TM), the quantity of beds available, the GDP, or the specific climatic conditions, the geographic location element directly affected the values.

For all energy efficiency measures to be implemented, specific regulations and policies must be in place. Consequently, in [9], they examined the primary obstacles to the adoption of different technologies that would increase energy efficiency in the context of China's hospital industry. They discovered that there is insufficient government backing for the laws and regulations utilized, suitable technology, and financial incentives. The previously described has emerged as a noteworthy hindrance to attaining enhanced energy efficiency. The authors suggested that in order to address this issue, policymakers take a multifaceted approach that addresses hospitals, projects, as well as technical and operational procedures in order to promote full engagement and support from all parties involved.

However, as noted in [10,11], one of the primary goals of energy policy at the local, state, and federal levels is to assess energy efficiency in the hospital sector. Thus, the conducted research seek to determine the energy efficiency of hospital buildings that reflects appropriate energy management and energy conservation measures (ECM). We were able to design and modify the criteria based on historical data by conducting an energy audit, which gave us insight into the current state of affairs. They found that the most effective way to measure a hospital's energy usage is to look at the indication that is based on the number of beds in the facility. While there are numerous technological approaches to increase energy efficiency, hospital energy auditors should begin with basic implementations. The primary obstacles to energy efficiency in healthcare institutions are outlined in [12].

Modelling of Hybrid Energy

The various models that are used to simulate, build, and regulate generation systems using unconventional renewable energy sources and how they are combined to create hybrid energy systems are covered in this section. The researchers [13, 14, 15, 16, 17, 18,] demonstrated that they selected a power supply system structure made up of module arrangements with solar panel arrangements. High-end establishments including office buildings, apartment complexes, and medical centers require the application of multi-criteria techniques to identify an acceptable and dependable system architecture. Integrated modeling, simulation, optimization, and control techniques were applied in [13,14,15,16,17,18] to build hybrid renewable energy systems, test their performance, and determine their cost. All things considered, the outcomes of their modeling and simulation work led to the development of an energy system that combines batteries, diesel power, and photovoltaic solar energy to satisfy a building's initial daily and annual AC requirement.

Simulators are an intriguing tool for assessing photovoltaic (PV) system performance. The Addis Boder Health Center's standalone photovoltaic system's full design was displayed in [19], where it was intended to power electrical demands. They proved that the only optimal and most efficient choice was the standalone photovoltaic system with battery storage. In this instance, they employed optimization techniques and the HOMER Software, accounting for the daily energy consumption. Because of the low operational costs and the economic component that represented the quantity of harmful gas emissions—in this case, a decrease in greenhouse gas emissions—the end result was a lower net cost.

Consequently, they came to the conclusion that installing photovoltaic systems to generate electricity is advised at rural locations far from the electrical distribution network [19] because of their reduced associated costs. A different approach to simulating photovoltaic (PV) systems is shown in [20], where Matlab / Simulink software was used to model and simulate PV modules and assemblies based on models represented by one and two diodes. They came to the conclusion that the models employed demonstrated how temperature and solar radiation affected the properties of the collection of P-V and I-V modules. The Energy Storage Systems (EES) used to supply energy to buildings can be classified according to three perspectives—global application, performance research, and optimization research.

The uses of photovoltaic (PV) systems are emphasized in [21] as viable substitutes for the provision of electrical energy in buildings. By utilizing energy storage technology, PV systems' oscillations in electric power generation are less noticeable. The latter makes it possible to match energy production to the building's needs. The mechanical, electrochemical, and electrical storage types are the main categories used to group these electrical energy storage systems. As a result, the authors [21] stressed the need to ensure adherence to particular specifications such application conditions, location, climate, storage needs, and the electrical load of the building.

Optimization of Hybrid System

Based on how people behave and how the building's workplaces are heated comfortably, hybrid PV-EES electrical systems are optimized to strengthen the robustness of the electrical systems in buildings. In this section, two types of optimization criteria—single- and multi-criteria—are utilized to optimize hybrid electrical systems, specifically the photovoltaic system, diesel generator, and battery system.

The use of cutting-edge instruments and optimization strategies to incorporate renewable energy sources into microgrids is highlighted in [22]. They emphasized in their research the fundamental system parameters that are related to the system's technical and financial performance and that must be taken into account in order to optimize it. It is possible to incorporate environmental characteristics like the reduced cost of emissions. By employing optimization approaches targeted at the creation and execution of resource management systems, optimization tools, metaheuristics, and heuristic techniques have made it possible to design a wide range of devices that aid in the optimization of hybrid systems with renewable energy components.

They were able to develop a broad framework for the formulation and categorization of various optimization techniques used with hybrid electrical systems in [23]. They reviewed energy management strategies (EMS) and system optimization for a fuel cell-equipped standalone integrated wind and solar energy system. The optimization process focuses on figuring out how to combine the system's parts to create a lucrative hybrid system. As a result, they were able to implement a guide that facilitates system optimization and establishes the energy management strategies (EMS) that are applied in the design of an independent fuel cell-integrated photovoltaic (PV) and wind energy (WT) system. Additionally, they emphasized that, in order to formulate the optimization issue and have a better grasp of the optimization problem executed, the design factors, limits, and goal functions must be accurately stated. PV systems installed in medical assistance institutions typically result in the formation of an electrical microgrid, according to a proposal made by [24], who provided a design technique for a micro-grid linked to the distribution network. The PV-Battery-Diesel Generator system that makes up this microgrid is based on how the energy management approach affects the system's individual components.

Another strong argument in favor of microgrid applications in healthcare facilities may be found in [25], where a technique for the techno-economic optimization of microgrid systems—specifically, those at the St. Mary Lacor hospital in Gulu, Uganda—is proposed. The Milan Polytechnic determined the range of solutions by using an optimization method based on their own Poli.NRG tool. The PV system's range is 0-3000 kWp with a step of 1 kW and the batteries' range is 0-3000 kWh with a step of 1 kWh. The DG's size is determined exogenously, and the most practical capacities are 200 and 250 kW. It is important to note that the microgrid they created was intended to supplement the public distribution system, reducing the likelihood of a blackout occurring within the hospital. It is important to assess a photovoltaic system's operation in locations with extremely unfavorable air circumstances so that its behavior may be recognized. That's why they put it forth in [26]. They explain the wintertime experiment conducted at the Kayenta Health Center in Navajo County, Arizona, USA, using a 100 kW photovoltaic system. According to the findings of their investigation, the photovoltaic system's average maximum power output is 30% lower in the winter than it is in the summer.

A microgrid's operation needs to be optimized in some way in order to provide a reliable alternative energy source. A methodology for applying the Monte-Carlo method to optimize hybrid off-grid systems (photovoltaic-diesel-battery systems) was presented in [27]. They emphasized that an ideal layout might result in a 28% decrease in energy expenses and a 54% decrease in the diesel fuel utilized by the generator, thereby lowering the pollutants released by these establishments. A strong case study was provided in [28], whereby the ideal configurations of renewable hybrid systems were assessed for use in rural health clinics (RHCs) spread across three remote villages in Nigeria that lacked network connectivity.

The hybrid PV/wind/diesel/battery system is the most economical setup, according to the authors, for powering the rural health clinics in Maiduguri and Enugu. On the other hand, the system at the Iseyin location was a hybrid PV/diesel/battery setup. Despite having two distinct hybrid systems, they emphasize that the ideal configurations they chose operate far more efficiently than the traditional autonomous diesel system in terms of cost and emission reduction.

In Medical Assistance Facilities, optimization strategies for microgrids are typically applied after a techno-economic review, as suggested in [29], has been completed. In a hospital in Malaysia, the combined heat and PV power system, the diesel generator, and the batteries were assessed. The authors [29] noted that a cogeneration system consisting of a hybrid photovoltaic system connected to the distribution network, a diesel generator, and batteries becomes a viable alternative for significant energy-consuming centers, like a hospital, based on the results of the simulation scenarios analyzed with HOMER software. It makes sense for this system to reduce greenhouse gas emissions from the atmosphere while still meeting load demand.

The authors [29] pointed out that the optimization of designed hybrid renewable energy systems can consist of optimization problems with multiple objectives, such as environmental management, control, or optimization system, as well as single-objective optimization problems, such as optimizing the size of system elements to minimize overall costs.

Researchers in [30], [31] looked into the drawbacks of putting a hybrid system into place. In order to use hybrid systems, optimization problems involving one or more objectives must be solved. Examples of these problems include sizing the system to minimize energy costs, controlling the system to balance the uncertainty of the energy produced, and lowering greenhouse gas emissions. All of these problems are based on multi-objective optimization techniques. They discovered that the most frequently utilized objective functions in the optimization of multiple objectives of hybrid renewable energy systems are system cost minimization and system reliability maximization. This is based on optimization theory, which is concerned with the mathematical study of problem-solving for minimum or maximum values of an objective function.

Hybrid PV - EES Systems: Optimization Methods And Algorithms

Several noisy nonlinear mathematical optimization issues in engineering and design cannot be solved efficiently with traditional optimization methods. However, metaheuristic algorithms like Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) have gained a lot of popularity since they appear to be quite effective at tackling these issues.

Two well-known heuristic algorithms, Genetic Algorithm (GA) and Particle Swarm (PSO), were compared in [32] with other, more recent metaheuristic algorithms, which are used to find optimal solutions to noisy non-linear optimization problems. These algorithms include the Gray Wolf Optimizer (GWO) algorithm, Firefly Algorithm (FA), and Brain Storm

Optimization (BSO). In the majority of test instances, GA and PSO fared really well, according to the authors. However, GWO also showed that it is a highly competitive algorithm capable of solving noisy non-linear optimization problems in terms of both runtime and precision. At runtime, FA is also a rather competitive algorithm. In contrast, FA's accuracy data indicated that several test functions yielded subpar results. Ultimately, BSO is an algorithm whose precision is acceptable but whose runtime is ineffective.

In [33], an enhanced heuristic classification is offered as a foundation for future studies to operate equitably heuristically. In order to identify distinctive characteristics that can aid in differentiating each heuristic among them, the study team created a thorough diagnosis of heuristic categorization schemes. They stress that having a thorough understanding of a heuristic's properties and search behavior is essential before putting it into practice.

The sizing procedures for hybrid renewable energy systems (independent and connected to the grid) were primarily examined in [34]. These methodologies are based on a combination of traditional, artificial intelligence, hybrid, and computational technologies.

In order to talk about operating strategy optimization for hybrid systems, we refer to [35,36,37,38,39,40,41,42, 43].The writers emphasized both traditional and cutting-edge optimization techniques applied to microgrid applications. They suggested that by employing these methodologies, various control optimization strategies may be put into practice to enhance the performance and integration of renewable energy sources into microgrids. As a result, numerous researchers have developed artificial intelligence, which has made it possible to optimize microgrid control and guarantee clients a sustainable supply of electricity.

To locate and size the distributed generation in a distribution system, the authors of [44] compared the metaheuristic approaches Tabu Search (TS), Scatter Search (SS), and Ant Colony (AC). The suggested approach was evaluated in IEEE systems with 13 nodes, comparing the results of the SS, TS, and AC algorithms. emphasizing that, in terms of solution correctness and convergence process, SS was superior to TS and AC.

Conclusions

The state of the art for hybrid systems that use unconventional renewable energy sources in sanitary installations is reviewed in this paper. The primary tasks, methods, and metrics for completing electricity consumption profiles and assessing energy efficiency in sanitary facilities have been determined. This has made it possible for us to pinpoint the various algorithms and optimization strategies based on heuristic and mathematical methods that are applied to hybrid electrical systems, thereby resolving issues with sizing, operating strategy, and energy management.

References:

1. Vaziri, Rezaee, & Monirian, ”Utilizing renewable energy sources effi- ciently in hospitals using demand dispatch”,in Renewable Energy, 2019.
2. Nils Christiansen *et. al*, “Electrical energy consumption and utilization time analysis of hospital departments and large scale medical equipment”, Energy and Buildings, Volume 131, 2016.
3. C. Shen, K. Zhao, J. Ge, and Q. Zhou, “Analysis of building energy consumption in a hospital in the hot summer and cold winter area,” in Energy Procedia, 2019, vol. 158, pp. 3735–3740.
4. A. G. Gonza´lez, J. Garc´ıa-Sanz-Calcedo, and D. R. Salgado, “Evaluation of energy consumption in German hospitals: Benchmarking in the public sector,” Energies, vol. 11, no. 9, Sep. 2018.
5. Yi Wang *et. al*, “Load profiling and its application to demand response: A review,” Tsinghua Sci. Technol., vol. 20, no. 2, pp. 117–129, Mar. 2016.
6. J. Garc´ıa-Sanz-Calcedo, M. Go´mez-Chaparro, and G. Sanchez-Barroso, “Electrical and thermal energy in private hospitals: Consumption indica- tors focused on healthcare activity,” Sustain. Cities Soc., 2019.
7. Arocas Sergio M., Coria Hoffmann Geraldine D. y Bosc Cristian, “Iden- tificacio´n de indicadores energe´ticos para el disen˜o de un programa de ahorro y eficiencia energe´tica en una Instalacio´n Hospitalaria”, Facultad de Ingenier´ıa UNLP,2019.
8. A. Gonza´lez Gonza´lez, J. Garc´ıa-Sanz-Calcedo, and D. R. Salgado, “A quantitative analysis of final energy consumption in hospitals in Spain,” Sustain. Cities Soc., vol. 36, pp. 169–175, Jan. 2018.
9. T. Wang, X. Li, P. C. Liao, and D. Fang, “Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers,” Energy, vol. 103, pp. 588–597, May 2016.

10. K. Bawaneh, F. Ghazi Nezami, M. Rasheduzzaman, and B. Deken, "En- ergy Consumption Analysis and Characterization of Healthcare Facilities in the United States," Energies, vol. 12, no. 19, p. 3775, Oct. 2019.
11. Hwang, Cho, and Moon, "Feasibility Study on Energy Audit and Data Driven Analysis Procedure for Building Energy Efficiency: Bench- Marking in Korean Hospital Buildings," Energies, vol. 12, no. 15, p. 3006, Aug. 2019.
12. A. Prudenzi, A. Fioravanti, and V. Caracciolo, "Resilient power in hospitals: The S. Giovanni addolorata general hospital case study," in 2017 AEIT International Annual Conference: Infrastructures for Energy and ICT: Opportunities for Fostering Innovation, AEIT 2017, 2017, vol. 2017-January, pp. 1–6. Energy and ICT: Opportunities For Fostering Innovation ,AEIT 2017,2017,vol.2017-January,pp.1-6.
13. B. N. Lobov, P. G. Kolpakhch'yan, S. A. Belokopytov, and A. D. R. Ali Madzhid, "A choice of the structure of the photovoltaic system for power supply," Russ. Electr. Eng., vol. 86, no. 7, pp. 398–402, Jul. 2015.
14. Giovanni Petrone, Carlos Andres Ramos-Paja, Giovanni Spagnuolo. Pho- tovoltaic Sources Modeling, Wiley-IEEE Press, 2017.
15. N.D. Kaushika , Anuradha Mishra & Anil K. Rai, Solar Photovoltaics, Springer International Publishing,2018.
16. Weidong Xiao,Photovoltaic Power System: Modeling, Design, and Con- trol,Wiley,2017.
17. Bo Zhao, Caisheng Wang, Xuesong Zhang,Grid-Integrated and Stan- dalone Photovoltaic Distributed Generation Systems: Analysis, Design, and Control,Wiley,2017.
18. C. Ghenai and M. Bettayeb, "Modelling and performance analysis of a stand-alone hybrid solar PV/Fuel Cell/Diesel Generator power system for university building," Energy, vol. 171, pp. 180–189, Mar. 2019.
19. M. Jariso, B. Khan, D. Tesfaye, and J. Singh, "Modeling and designing of stand-alone photovoltaic system: CaseStudy: Addis Boder health center south west Ethiopia," in Proceedings of the International Conference on Electronics, Communication and Aerospace Technology, ICECA 2017, 2017, vol. 2017-January, pp. 168–173.
20. A. Bouraiou, M. Hamouda, A. Chaker, M. Sadok, M. Mostefaoui, and

S. Lachtar, “Modeling and Simulation of Photovoltaic Module and Array Based on One and Two Diode Model Using Matlab/Simulink,” in Energy Procedia, 2015, vol. 74, pp. 864–877.

21. J. Liu, X. Chen, S. Cao, and H. Yang, “Overview on hybrid solar photovoltaic-electrical energy storage technologies for power supply to buildings,” Energy Conversion and Management, vol. 187. Elsevier Ltd,
22. pp. 103–121, 01-May-2019.
23. A. H. Fathima and K. Palanisamy, “Optimization in microgrids with hybrid energy systems - A review,” Renewable and Sustainable Energy Reviews, vol. 45. Elsevier Ltd, pp. 431–446, 01-May-2015.
24. A. L. Bukar and C. W. Tan, “A review on stand-alone photovoltaic- wind energy system with fuel cell: System optimization and energy
25. management strategy,” Journal of Cleaner Production, vol. 221. Elsevier Ltd, pp. 73–88, 01-Jun-2019.
26. M. Hijjo, F. Felgner, and G. Frey, “PV-Battery-Diesel microgrid layout design based on stochastic optimization,” in 2017 6th International Conference on Clean Electrical Power: Renewable Energy Resources Impact, ICCEP 2017, 2017, pp. 30–35.
27. A. Bosisio, M. Moncecchi, G. Cassetti, and M. Merlo, “Microgrid design and operation for sensible loads: Lacor hospital case study in Uganda,”
28. Sustain. Energy Technol. Assessments, vol. 36, p. 100535, Dec. 2019
29. S. V. Cotto and W. J. Lee, “Microgrid modular design for Tribal Healthcare facilities: Kayenta Health Center used as guidance for concept model for Navajo Nation,” in 2017 IEEE Industry Applications Society Annual Meeting, IAS 2017, 2017, vol. 2017-Janua, pp. 1–8.
30. R. Dufo-Lo´pez, E. Pe´rez-Cebollada, J. L. Bernal-Agust´ın, and I. Mart´ınez-Ruiz, “Optimisation of energy supply at off-grid healthcare facilities using Monte Carlo simulation,” Energy Convers. Manag., vol. 113, pp. 321–330, Apr. 2016.
31. L. Olatomiwa, “Optimal configuration assessments of hybrid renewable power supply for rural healthcare facilities,” Energy Reports, vol. 2, pp. 141–146, nov. 2016
32. N. M. Isa, H. S. Das, C. W. Tan, A. H. M. Yatim, and K. Y. Lau,
33. “A techno-economic assessment of a combined heat and power photo- voltaic/fuel cell/battery energy system in Malaysia hospital,” Energy, vol. 112, pp. 75–90, Oct. 2016

34. Tuba Tezer, Ramazan Yaman, Gu¨ls¸en Yaman, Evaluation of approaches used for optimization of stand-alone hybrid renewable energy systems, Renewable and Sustainable Energy Reviews, Volume 73,2017,Pages 840- 853.
35. Jijian Lian, Yusheng Zhang, Chao Ma, Yang Yang, Evance Chaima, A review on recent sizing methodologies of hybrid renewable energy systems, Energy Conversion and Management, Volume 199,2019.
36. V. Sai et al., ”Comparative Study on Recent Development of Heuristic Optimization Methods,” 2016 Third International Conference on Comput- ing Measurement Control and Sensor Network (CMCSN), Matsue, 2016,
37. pp. 68-71.
38. E. M. Nazri and S. Murairwa, ”Classification of heuristic techniques for performance comparisons,” 2016 12th International Conference on Mathematics, Statistics, and Their Applications (ICMSA), Banda Aceh, 2016, pp. 19-24.
39. Samir M. Dawoud, Xiangning Lin, Merfat I. Okba, Hybrid renewable microgrid optimization techniques: A review, Renewable and Sustainable Energy Reviews,Volume 82, Part 3, 2018,Pages 2039-2052.
40. S. Leonori, M. Paschero, F. M. Frattale Mascioli, and A. Rizzi, “Opti- mization strategies for Microgrid energy management systems by Genetic Algorithms,” Appl. Soft Comput. J., vol. 86, p. 105903, Jan. 2020.
41. C. Gamarra and J. M. Guerrero, “Computational optimization techniques applied to microgrids planning: A review,” Renewable and Sustainable Energy Reviews, vol. 48. Elsevier Ltd, pp. 413–424, 01-Aug-2015.
42. Jp. Clean, “Optimised controller for renewable energy sources integration into microgrid: Functions, constraints and suggestions,”, Feb. 2020.
43. Zack Stokes, Abhyuday Mandal, Weng Kee Wong,Using Differential Evolution to design optimal experiments,Chemometrics and Intelligent Laboratory Systems,Volume 199,2020.
44. J. Jobanputra and C. Kotwal, ”Optimal Power Dispatch using Particle Swarm Optimization,” 2018 International Conference on Smart Electric Drives and Power System (ICSEDPS), Nagpur, 2018, pp. 157-161.
45. T. M. Mohan and T. Nireekshana, ”A Genetic Algorithm for Solving Optimal Power Flow Problem,” 2019 3rd International conference on Electronics, Communication and Aerospace Technology (ICECA), Coim- batore, India, 2019, pp. 1438-1440.

46. Sara Ghaem Sigarchian, Matthew S. Orosz, Harry F. Hemond, Anders Malmquist, Optimum design of a hybrid PV–CSP–LPG microgrid with Particle Swarm Optimization technique, Applied Thermal Engineer- ing,Volume 109, Part B,2016,Pages 1031-1036.
47. Maher Azaza, Fredrik Wallin, Multi objective particle swarm optimization of hybrid micro-grid system: A case study in Sweden, Energy, Volume 123, 2017,Pages 108-118.
48. Juan Uparela , Samuel Hernandez, Ingrid Oliveros, Jose Soto Ortiz, Elvin Jimenez, Leandro Zurek,.“Sistema Fotovoltaico no interconectado: caso Providencia”. 10.18687/LACCEI2018.1.1.166.(2018).
49. Luis Lo´pez D´ıaz , Jose Doria-Garcia, Carlos Pimienta, Adriana Arango-Manrique.“Distributed Generation Allocation and Sizing: A Compari- son of Metaheuristics Techniques”. 1-6. 10.1109/EEEIC.2019.8783934. (2019).

Chapter-19:

Hydroelectric Energy in India: A Review

Bikash Panja

Swami Vivekananda University, Barrackpore, North 24 Pargana, Kolkata-700121, India

*Corresponding author: bikashpanjame@gmail.com

Hydroelectric Energy in India: A Review

Bikash Panja

Swami Vivekananda University, Barrackpore, North 24 Pargana, Kolkata-700121, India

*Corresponding author: bikashpanjame@gmail.com

Abstract

The history of hydroelectric energy in India has defined a pivotal role as contributing to the harnessing development for renewable sources and helping meet increasing demand on an environmentally friendly balance. Here, we put forth one of the most systematic literature reviews to discuss about development and status today as well potential possibilities in future related to hydroelectric energy in India. In this paper, history of hydroelectric power generation and the relevant regulatory and policy till date have been described with brief environmental-social impacts as well as technology-upgradation. The book also deals with sector issues like environmental degradation, resettlement and impact of climate –change on water availability. This review assesses India's hydroelectric energy policy and provides some suggestions on how best the country could utilise this renewable resource to help fill its future energy requirements while addressing sustainability and social equity consequences.

Keywords: Hydroelectric energy, water resources, sustainability, environmental impact.

1. Introduction

India Hydroelectricity is one of the oldest forms of renewable energy sector in India India: Owing to its geographical context of many rivers flowing through mountain areas, India is best placed in the world for hydroenergy generation (Kumar & Katoch 2015). hydroelectric power is something the country has long understood as a way to meet its energy sources in clean and renewable ways. Hydroelectric power has been an important part of the Indian policy efforts in recent years to diminish its reliance on fossil fuels and transition towards a greener energy mix (Bhattacharyya, 2011). India has an estimated hydroelectric energy potential of around 148,700 megawatts (MW) and therefore is the fifth largest country in terms of its vast reservoirs for producing hydroelectricity on a global scale (Central Electricity Authority, 2020). This review focuses on the development, present status and problems of hydroelectric energy in India. The paper will also delve into policy frameworks, technological advancement and climate change impacts thereby providing a larger canvas of hydroelectric power future in India.

Hydraulic power station: Hydroelectric power generation in India had started early this century, with establishment of first hydroelenctric plant Darjeeling way back in 1897.(Rao,2017) The shift was the start of hydroelectric figuring in to India energy matrix. Since then, the country has steadily increased its hydroelectric capacity, particularly after independence, when large-scale projects like the Bhakra-Nangal Dam were developed as part of India's five-year plans (Batra, 2016). The development of hydroelectric infrastructure gained momentum in the post-independence era, with dams constructed to support irrigation, flood control, and electricity generation. During the 1960s and 1970s, hydroelectric projects were seen as symbols of modernity and progress, exemplified by iconic projects like the Hirakud and Tehri dams (Biswas, 2012). The construction of large dams led to the rise of multi-purpose river valley projects aimed at integrated water resource management. However, the 1990s saw a shift towards smaller hydroelectric projects as concerns about the environmental and social impacts of large dams became more pronounced (Alagh, 2013). Small hydropower plants (SHPs), defined as having capacities of up to 25 MW, have been promoted as a less ecologically disruptive alternative, especially for remote regions with untapped water resources (Sharma & Thakur, 2017). Hydroelectric power currently accounts for around 13% of India's total installed power capacity, contributing approximately 45,699 MW as of 2021 (Central Electricity Authority, 2021). Although its share in the overall energy mix has declined due to the rapid expansion of thermal and solar energy, hydroelectricity remains crucial for providing peaking power, grid stability, and balancing variable renewable energy sources such as solar and wind (Mohan, 2019).

2. Policy Framework and Regulatory Landscape

India’s approach to hydroelectric development is shaped by national energy policies, regulations, and international agreements. The government has introduced several initiatives to encourage the development of both large and small hydroelectric projects.

2.1 National Policies and Programs

The **Electricity Act of 2003** provides the overarching framework for electricity generation, transmission, and distribution in India, promoting private sector participation in the energy sector, including hydroelectricity (Bhattacharyya, 2011). The policy of 2008, i.e., National

Hydroelectric Power Policy specifically deals with the development of large hydro projects and provides provisions for tariff structuring, power purchase agreement and incentives to state-owned utilities (Ministry Of Power,2008).

Recently, the government has been encouraging small hydro projects through its Small Hydro Power Program under the Ministry of New and Renewable Energy (MNRE). The objective of the programme is to provide financial assistance and technical support for development of small hydro projects (upto 25 MW capacity) in regions such as hilly States including North Eastern Region that are considered under developed from perspective of their exploitation of Hydroelectric potential etc. (MNRE,2020).

2.2 International Commitments and Climate Goals

The Paris Agreement — India is a signatory to this pact framed by world leaders on climate change action plan seeking to limit global warming and reduce greenhouse gas emissions. India has made a new commitment to the Paris Agreement, targeting 40% of electric power supply from non-fossil resources by 2030 and with hydroelectric firmly in mind (Government of India, 2015). Additionally, the National Action Plan on Climate Change (NAPCC) underlines that developing renewable sources of energy and water resources management are core strategies to mitigate climate change with hydropower being one the significant measures for clean power generation (Goel & Kumar, 2019).

3. Environmental and Social Impacts of Hydroelectric Projects

Hydroelectric projects, and large dams particularly, are often associated with considerable environmental and social effects. Given that hydropower is a clean power source, its exploitation can impact ecosystems and societies at large. Among the most notorious environmental concerns are dams and their effects on rivers. Ghosh & Biswas (2014) argue that the development of large dams, a type of grey infrastructure can result in habitat destruction change water flow patterns and decrease biodiversity. Fish migration will be obstructed, aquatic life affected and wetlands lost as a result of the change to natural river systems. Moreover, the dams create reservoirs known to emit Methane (CH_4), a powerful greenhouse gas that results from both aerobic and anaerobic decomposition of organic matter buried by water level rising after filling in operation.

Hydroelectric projects also cause deforestation, as the building of dams and required reservoirs to create them often require flooding large swaths of forest. This leads to deforestation and depletion of biodiversity. soil erosion occurs as the rate of production increases, locality loses water or nutrients creating impaired local climate (Shah 2013).

Few hydropowers projects — particularly the larger ones, including dams in place of run-of-river schemes — have escaped criticism for their social consequences. Local population displacements: One of the most debated and controversial themes in literature (Roy, 1999) leading to strong social conflicts. Millions of people, especially the indigenous and land dependent population have been displaced due to construction of large dams in India (Venkateswarlu, 2018).

This has resulted in displacement of people and despite compensation or rehabilitation provided by the government, resettlement of displaced communities have often not been up to standard with long term no-socioeconomic undo costs (Sharma, 2019). Displacement leads to various problems such as deprivation of land, resources and identity enhancing already existing poverty (Baviskar 1995).

4. Technological Advancements in Hydroelectric Energy

Improvements in hydroelectric power based on technological innovation may be able to reduce some of the environmental and social effects, as well boosting efficiency and reliability.

4.1 Pumped Storage Hydropower (PSH)

Pumped storage hydropower or PSH is a novel technology used for the purpose of storing accumulated surplus electrical energy that's been delivered during peak hours to be stored as gravitational potential up within at upper reservoir by pumping water from lower reservoirs. At times of high-electricity demand, the water is released to flow through turbines used for electricity generation. Since supply and demand are key to grid stability, PSH is an ideal complementary technology for other renewable energy types such as wind and solar (Liu & Pang, 2015). The Tehri Pumped Storage Project in Uttarakhand (CEA, 2021) has several constructive projects of PSH making India a considerable share-holder in the promising potential for PHS.

4.2 Small Hydropower Technology

Improvements in small hydro technology have made it easier to establish projects where the watersheds and ecological sensitivity are higher. Technological improvements in both prefabrication practices and modular assembly have also been suggested as ways to reduce building time (Singh et al. 2018). Run-of-the-river projects are also options, as they do not involve new large dams and reservoirs like conventional hydropower.

4.3 Hybrid Hydro-Solar Systems

A hybrid hydro-solar system that works by combining hydropower generation with solar power sources to develop a more robust and high-efficient energy & electricity generating infrastructure. These systems work in tandem with existing hydroelectric infrastructure by incorporating solar panels to maximize the use of water resources for generating electricity while simultaneously smoothing out some of the intermittency issues associated with just using solar power (Gleick, 2019). The technology is especially relevant in regions like India, which have monsoon-dependent river systems and variable water availability with seasonal peaks.

5. Climate Change and Water Availability

The change in climate is a big reason why the future of hydroelectric power may be called into question for India. Variability in precipitation patterns, other climatic factors such as glacial melt and the number of extreme weather events can all change how much water is available to create hydropower (Immerzeel et al., 2010). The northern regions of India, mostly the Himalayas are highly dependent on Glacial Meltwater for their rivers. Glaciers are melting and decreasing the dry-season runoff from rivers at an alarming rate due to global temperature rise (Bolch et al., 2012). It apply to hydroelectric power in particular, with implications for the overall reliability of energy supply through states like Himachal Pradesh or Uttarakhand where hydropower drives over 90% of electricity (Chadha, 2020). The Indian monsoon season is vital for restoring natural water resources, on which hydro power projects are based. But climate change appears to be making monsoons less predictable, sparking heavier rainfall in some areas and leaving others parched (Roxy et al.. 2017). This variation leads not only to water scarcity but also flooding, both of which increase the challenges in operation and maintenance of hydroelectric power plants (Goswami & Ghosh 2021).

Conclusion

The hydropower sector is an integral part of India's renewable energy space, and it holds much potential for sustainable generation. We have some risks to overcome: from environmental and social challenges, to technological limitations and implications of climate change. If India can start using sustainable practices, involving the affected communities and taking help of technological innovations it could develop its hydroelectric potential and tackle issues more widely related to sustainability as well as equity. While hydroelectric power is not without controversy in India, as the country moves towards a greener energy mix it will continue to play an important role for decades yet with helping improve Indian Energy security and fighting climate change.

References

1. Alagh, Y. K. (2013). Water policy and reforms in India: An agenda for the future. *Indian Journal of Agricultural Economics, 68*(1), 70-78.
2. Batra, S. (2016). The evolution of India's hydroelectric infrastructure: A historical review. *Renewable Energy Journal, 45*(4), 233-245.
3. Baviskar, A. (1995). In the belly of the river: Tribal conflicts over development in the Narmada Valley. *Oxford University Press*.
4. Barros, N., Cole, J. J., Tranvik, L. J., Prairie, Y. T., Bastviken, D., Huszar, V. L. M., ... & Roland, F. (2011). Carbon emission from hydroelectric reservoirs linked to reservoir age and area. *Nature Geoscience, 4*(9), 593-596.
5. Bhattacharyya, S. C. (2011). *Energy economics: Concepts, issues, markets and governance*. Springer Science & Business Media.
6. Biswas, A. (2012). Dams and development: Understanding the nexus between infrastructure and environment in India. *Environmental Research Letters, 7*(3), 1-10.
7. Bolch, T., Kulkarni, A., Kääb, A., Huggel, C., Paul, F., Cogley, J. G., ... & Stoffel, M. (2012). The state and fate of Himalayan glaciers. *Science, 336*(6079), 310-314.
8. Central Electricity Authority (CEA). (2020). Annual Report. Government of India.

9. Chadha, A. (2020). Glacial melt and its impact on hydropower generation in the Himalayan region. *Journal of Water Resources, 12*(2), 144-159.
10. Ghosh, P., & Biswas, A. (2014). Hydropower development in India: Environmental and social perspectives. *Energy Policy Journal, 72*(5), 39-46.
11. Goel, R. K., & Kumar, R. (2019). National action plan on climate change: Addressing the hydropower sector in India. *Sustainable Development Journal, 27*(1), 21-30.
12. Government of India. (2015). India's Intended Nationally Determined Contribution (INDC).
13. Goswami, B. N., & Ghosh, S. (2021). Monsoon variability and its impact on hydropower in India. *Climate Dynamics Journal, 54*(1), 101-115.
14. Immerzeel, W. W., van Beek, L. P., & Bierkens, M. F. (2010). Climate change will affect the Asian water towers. *Science, 328*(5984), 1382-1385.
15. Kumar, P., & Katoch, S. S. (2015). Hydroelectric energy in India: An overview of past and future developments. *Renewable and Sustainable Energy Reviews, 51*, 1117-1128.
16. Liu, H., & Pang, Q. (2015). Development and prospects of pumped storage hydropower in India. *Energy Policy, 77*, 387-396.
17. Ministry of Power. (2008). National Hydroelectric Power Policy. Government of India.
18. MNRE. (2020). Small Hydro Power Program. Ministry of New and Renewable Energy, Government of India.
19. Mohan, V. (2019). The future of hydropower in India: Opportunities and challenges. *Energy Studies Journal, 19*(3), 65-82.
20. Rao, P. S. (2017). India's first hydroelectric project: The Darjeeling experience. *Indian Journal of Energy Studies, 34*(2), 124-131.
21. Roxy, M. K., Ghosh, S., Pathak, A., Athulya, R., & Mujumdar, M. (2017). A review of monsoon variability and its impact on hydropower generation in India. *Water Resources Research, 53*(5), 3657-3677.
22. Roy, A. (1999). *The greater common good*. Penguin.
23. Shah, A. (2013). Deforestation and environmental impacts of large dams in India. *Environmental Science Journal, 22*(4), 299-312.
24. Sharma, R., & Thakur, N. (2017). Small hydroelectric plants: Potential and challenges in India. *Energy and Environment Journal, 28*(1), 55-64.

25. Singh, A., Kumar, S., & Rana, N. (2018). Technological advancements in small hydroelectric energy systems: A review. *Journal of Cleaner Energy, 32*(3), 145-157.
26. Venkateswarlu, S. (2018). Hydroelectric development and displacement: A study of rehabilitation policies in India. *Journal of Social and Economic Studies, 34*(1), 97-114.

Chapter-20:

Comparative Analysis of NOT Gate Performance Using GPDK45 and GPDK180 Technologies: A Virtuoso-Based Study

Sk Babul Akhtar

[1]*Swami Vivekananda University, Barrackpore, 700121*

Email: babula@svu.ac.in

Comparative Analysis of NOT Gate Performance Using GPDK45 and GPDK180 Technologies: A Virtuoso-Based Study

Sk Babul Akhtar

[1]*Swami Vivekananda University, Barrackpore, 700121*

Email: babula@svu.ac.in

Abstract: This paper presents a detailed comparative analysis of the NOT gate performance using two distinct process design kits (PDKs): GPDK45 and GPDK180. The study leverages Cadence Virtuoso software to design and simulate the NOT gate, assessing critical performance parameters such as propagation delay, power consumption, and area. The methodology involves creating the schematic and layout for the NOT gate using both GPDK45 and GPDK180, followed by generating symbols and constructing circuits to observe the gate's behavior under varying conditions. The analysis includes input-output characteristics, DC response, and transient analysis to determine the gate's time delay and overall efficiency. Results indicate significant differences in performance, where the GPDK45 technology demonstrates superior speed and reduced area at the cost of increased power consumption compared to GPDK180. These findings highlight the trade-offs involved in selecting a technology node for specific applications, providing valuable insights for designers aiming to optimize digital circuits in advanced semiconductor technologies. This research contributes to the ongoing efforts to scale down semiconductor devices while maintaining high performance and energy efficiency. It serves as a reference for engineers and researchers working on digital circuit design, offering a comprehensive comparison that underscores the importance of technology choice in designing fundamental logic gates.

Introduction

The relentless pursuit of smaller, faster, and more efficient semiconductor devices has driven the evolution of integrated circuit (IC) technology (Walter, J. G., Alwis, L. S., Roth, B., & Bremer, K. 2020) across multiple generations. As technology scales down, each successive process node offers distinct advantages and challenges, influencing the design and performance of digital circuits. Among the fundamental building blocks of digital logic, the NOT gate (or inverter) plays a crucial role (Liu, Y. 2021, January), often serving as a benchmark for evaluating the performance of different process technologies (Gray, P. R., Hurst, P. J., Lewis, S. H., & Meyer, R. G. 2024). In this paper, we focus on a comparative analysis of the NOT gate using two process design kits (PDKs): GPDK45 and GPDK180.

GPDK45, a 45nm technology node (Badiger, N. A., & Iyer, S. 2024), represents a more advanced and scaled-down process compared to GPDK180, which is based on a 180nm technology node. The comparison of these two nodes (Nidagundi, J. C. 2021) is particularly relevant as designers must choose between the reduced area and enhanced speed offered by smaller nodes like GPDK45, and the potentially lower power consumption and simpler fabrication process associated with larger nodes like GPDK180.

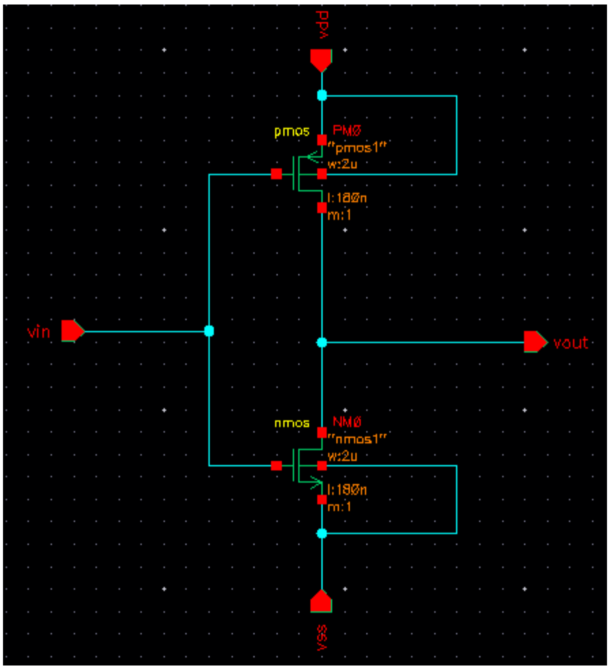
The study employs Cadence Virtuoso (Maity, I. 2024), a leading electronic design automation (EDA) tool, to design, simulate, and analyze the performance of the NOT gate in both technologies. The NOT gate's schematic, symbol, layout, and corresponding input-output characteristics (Mirhoseini, A., Goldie, A., Yazgan, M., Jiang, J. W., Songhori, E., Wang, S., ... & Dean, J. 2021) are meticulously developed and examined to assess key performance parameters such as propagation delay, power dissipation, and area efficiency. By analyzing the DC response and transient characteristics, this work provides a comprehensive understanding of how scaling impacts the performance of basic logic gates. The results of this study will offer valuable insights for circuit designers, aiding in the decision-making process when selecting an appropriate technology node for specific applications. Furthermore, this research contributes to the broader discourse on the trade-offs inherent in semiconductor scaling, particularly as the industry approaches the physical and economic limits of Moore's Law.

Overview

Schematic Drawing

The schematic of a NOT gate, also known as an inverter, is a fundamental design in digital electronics. The NOT gate inverts its input signal; a high input (logic 1) results in a low output (logic 0), and a low input (logic 0) results in a high output (logic 1). This basic operation is crucial in various digital systems, making the NOT gate a key component in logic design. To design the schematic of a NOT gate using Cadence Virtuoso (Kajal, & Sharma, V. K. 2021), create a new library where all your design files will be stored. Within this library, create a new cell, which can be named "NOT_gate_schematic" or another preferred name. In the schematic editor, select the necessary components, typically an NMOS transistor and a PMOS transistor, which together form the core of the CMOS-based NOT gate.

Start by configuring the transistors. Place the PMOS transistor with its drain connected to the output node and its source ready to connect to the supply voltage (VDD). Next, place the NMOS transistor with its drain also connected to the output node and its source ready to connect to the ground (GND). The gates of both transistors should be connected together to form the input of the NOT gate. This common gate connection ensures that both transistors receive the same input signal. After configuring the transistors, connect them appropriately using wires. The output is taken from the junction between the PMOS and NMOS drains. It is crucial to ensure that the schematic is accurately connected to reflect the intended design.



The resulting schematic (Fig. 1) illustrates the configuration of the PMOS and NMOS transistors in a CMOS inverter (Mamo, T. M., & Zhang, N. 2022, April), showing how they are interconnected to perform the logic inversion.

Working of the NOT Gate

The operation of the NOT gate (Wu, C. J., Liu, C. P., & Ouyang, Z. 2012) is based on the complementary behavior of the PMOS and NMOS transistors:

1. When the input is low (logic 0): The NMOS transistor is turned off, and the PMOS transistor is turned on. This causes the output to be pulled high, resulting in a logic 1 at the output.

2. When the input is high (logic 1): The NMOS transistor is turned on, and the PMOS transistor is turned off. This causes the output to be pulled low, resulting in a logic 0 at the output.

This complementary switching ensures that the output always presents the opposite logic level of the input, thereby achieving the desired inversion function of the NOT gate.

Symbol Creation

In digital circuit design, creating a symbol for the NOT gate is a crucial step that allows for easier integration of the gate into larger circuits. The symbol provides a simplified and standardized representation of the schematic, making it easier to use the NOT gate in various circuit designs (Dolan-Gavitt, B., Leek, T., Zhivich, M., Giffin, J., & Lee, W. 2011, May) without needing to repeatedly draw its internal structure.

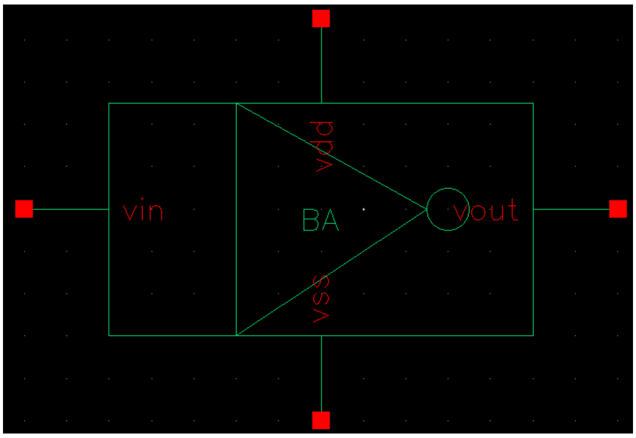


Fig. 2 Symbol of NOT Gate

After completing the schematic, the next step is to create the symbol for the NOT gate. Begin by opening the Symbol Editor in Virtuoso through the "Create Cellview" option and selecting "Symbol" as the view type. This action will open a blank canvas where you can design the symbol that represents the NOT gate. Typically, a NOT gate is depicted by a triangle pointing to the right, with a small circle at its output to signify the inversion function. Using the drawing tools in the Symbol Editor, draw a triangle to form the body of the NOT gate and add a small circle at the output to represent the inversion.

Once the shape is drawn, the next step is to define the input and output pins. Place a pin on the left side of the triangle, labeled as "In" or another appropriate name, to represent the input of the NOT gate. Similarly, place a pin on the right side of the triangle, labeled as "Out," to represent the output. Ensure that these pins are properly aligned with the symbol and correspond correctly to the input and output terminals of the underlying schematic. After placing the pins, customize the symbol properties as needed, including adding labels and adjusting pin names to ensure the symbol's appearance adheres to standard design conventions. Once the symbol design is complete, save it and verify that it is correctly associated with the schematic, ensuring that the input and output pins on the symbol map accurately to the corresponding nodes in the schematic.

The resulting symbol (Fig. 2) provides a clean and intuitive representation of the NOT gate, making it easy to use in subsequent circuit designs. This symbol abstracts away the detailed schematic, allowing designers to focus on higher-level circuit functionality without being bogged down by lower-level details.

Circuit Design

After creating the schematic and symbol for the NOT gate, the next step is to use the symbol to design a complete circuit. This stage involves integrating the NOT gate (Gupta, P., Ahluwalia, P., Sanwal, K., & Pande, P. 2015) into a larger circuit environment, where it can interact with other components and be subjected to various input conditions. The symbol simplifies this process, enabling the designer to focus on the overall circuit functionality without worrying about the internal complexities of the NOT gate.

Circuit Design in Virtuoso

To design a circuit using the NOT gate symbol in Cadence Virtuoso, begin by creating a new schematic cell within your project library, naming it appropriately, such as "NOT_gate_circuit." Once the new cell is created, open the Schematic Editor and place the NOT gate symbol that you previously designed onto the schematic canvas. This symbol encapsulates the entire NOT gate, representing the internal transistor-level details. Next, connect the power supplies by adding VDD and GND pins to the circuit. These pins will connect to the appropriate terminals of the NOT gate symbol, effectively powering the internal transistors. Specifically, the VDD pin should connect to the source of the PMOS transistor, and the GND pin should connect to the source of the NMOS transistor, both of which are implicitly handled by the symbol. Following the power connections, add an input signal by placing an input source component, such as a pulse generator or a DC voltage source, onto the schematic. This input source will provide the signal to the NOT gate by connecting its output to the input pin ("In") of the NOT gate symbol, driving the logic operation of the gate.

Finally, connect an output load, such as a capacitor or resistor, to the output of the NOT gate. This load simulates realistic circuit conditions and is connected to the output pin ("Out") of the NOT gate symbol. The output signal will then reflect the inverted input, producing the expected logic level. Ensure that all components are properly wired together, with the input source connected to the input pin of the NOT gate and the output pin connected to the load and any additional measurement probes needed for simulation. The resulting circuit design in Fig 3 effectively uses the NOT gate symbol to create a functional digital circuit that can be analyzed for various performance parameters. This circuit design phase demonstrates how the NOT gate behaves in a practical setting, with real-world inputs and outputs.

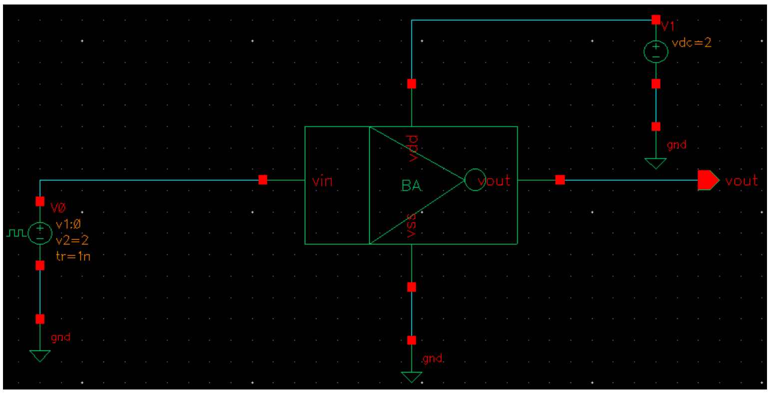


Fig. 3 Circuit Design of NOT Gate

Layout Design

The layout design is a critical step in the IC design process, where the schematic of the NOT gate is transformed into a physical representation (Gusmao, A., Canelas, A., Horta, N., Lourenco, N., & Martins, R. 2021, July) that can be fabricated on silicon. The layout defines the geometric placement of transistors, interconnects, and other components, ensuring that the circuit meets the required performance and area constraints. In this section, we will discuss the layout design for the NOT gate using both GPDK45 and GPDK180 technologies, with reference to Fig. 4 and Fig. 5.

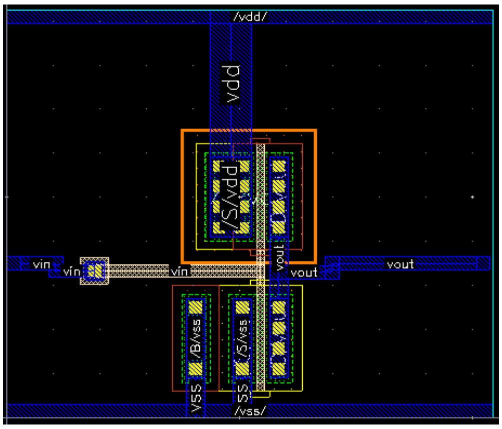


Fig. 4 Layout Design in gpdk180

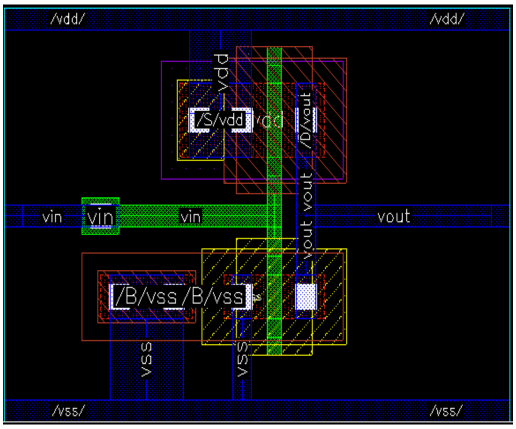


Fig. 5 Layout Design in gpdk45

Layout Design in Virtuoso

To create the layout of the NOT gate, the following steps are typically followed in Cadence Virtuoso:

1. Layout Editor Initialization: Open the Layout Editor in Virtuoso and create a new layout view corresponding to the NOT gate schematic. This layout view will be used to place and connect the various layers of the CMOS transistors.

2. Transistor Placement:

    1. For both GPDK45 and GPDK180, place the PMOS and NMOS transistors according to the design rules specific to each technology. The transistors should be positioned to minimize area and ensure efficient routing of connections.

    2. GPDK45 Layout (Fig. 4): In the 45nm technology node, transistors are smaller, allowing for a more compact layout. The distances between the source, drain, and gate regions are minimized, leading to a denser arrangement. The reduced feature size enables more aggressive scaling, which can reduce parasitic effects but requires precise alignment and careful attention to design rules.

    3. GPDK180 Layout (Fig. 5): In the 180nm technology node, the transistors are larger, resulting in a more spacious layout. The greater separation between elements simplifies the routing process but consumes more area. This

technology is less prone to variations and manufacturing defects, making the layout process more straightforward, though less optimized in terms of density.

3. Interconnect Routing:

    1. Connect the source, drain, and gate terminals of the transistors using metal layers.

    2. In GPDK45, the interconnects are narrower, requiring advanced routing strategies to avoid signal interference and maintain performance. The smaller dimensions necessitate multiple metal layers to effectively route the signals without introducing significant resistance or capacitance.

    3. In GPDK180, the wider interconnects allow for easier routing but can introduce more parasitic capacitance, potentially affecting the circuit's speed. The layout is generally more forgiving, allowing for simpler design rules.

Differences Between GPDK45 and GPDK180 Layouts

The primary differences between the layouts for GPDK45 and GPDK180 technologies lie in their scale, density, and complexity:

1. Density: GPDK45 allows for a denser layout, with smaller transistors and narrower interconnects. This results in a more compact design that can fit into a smaller area, which is advantageous for high-performance applications where space is at a premium. In contrast, GPDK180 has a less dense layout due to the larger feature sizes, which leads to a more spread-out design.

2. Routing Complexity: The GPDK45 layout requires more sophisticated routing strategies to manage the narrower metal layers and closer proximity of components. This can lead to increased design complexity and the need for multiple metal layers. GPDK180, with its wider interconnects and larger spacing, is generally easier to route but at the cost of increased parasitic capacitance and a larger overall footprint.

3. Design Rules: GPDK45 imposes stricter design rules (Yi, M. A. S., Hussin, R., Ahmad, N., & Rokhani, F. Z. 2021, September) due to the smaller feature sizes, which necessitate more precise alignment and higher resolution lithography.

GPDK180, with its more relaxed design rules, offers greater tolerance for variations but does not achieve the same level of miniaturization and performance as GPDK45.

Results and Discussion

In this section, we present a detailed comparison of the NOT gate's performance when implemented using GPDK45 and GPDK180 technologies. The comparison focuses on the output waveform, DC response, and propagation delay, which are critical parameters for evaluating the effectiveness and efficiency of the gate in different technology nodes. The output graph and DC response are shown in Fig. 6 and Fig. 7, respectively.

Output Waveform Analysis

The output waveforms of the NOT gate, as shown in Fig. 6, provide insight into how the gate responds to a given input signal in both GPDK45 and GPDK180 technologies. The waveform represents the gate's ability to invert the input signal and transition between logic levels.

1. GPDK45: The output waveform in GPDK45 technology demonstrates a sharper transition between logic levels. The gate switches quickly from high to low and low to high, reflecting the high-speed performance of the 45nm node. The rise and fall times are significantly reduced compared to GPDK180, which is indicative of faster operation and higher frequency capability. This quick response is essential in high-performance applications where timing precision is critical.
2. GPDK180: In contrast, the GPDK180 output waveform shows a slower transition between logic levels. The rise and fall times are longer, reflecting the inherently slower operation of the 180nm technology. This slower switching speed can lead to less precise timing in circuits, making GPDK180 more suitable for applications where speed is not the primary concern, and where power efficiency and robustness are more critical.

The sharper transitions in GPDK45 translate to improved performance in high-speed digital circuits, while the more gradual transitions in GPDK180 may contribute to reduced power consumption but at the cost of speed.

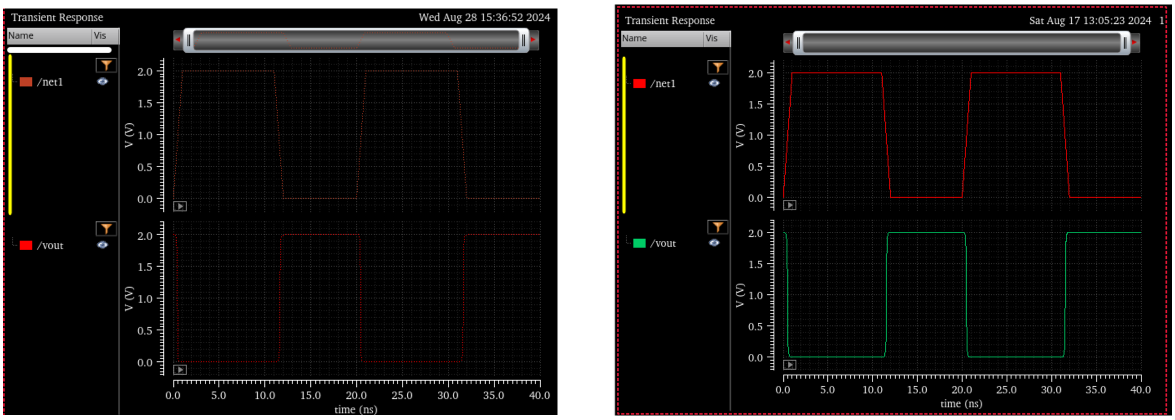


Fig. 6 Transient output waveform for gpdk180 (left) and gpdk45 (right)

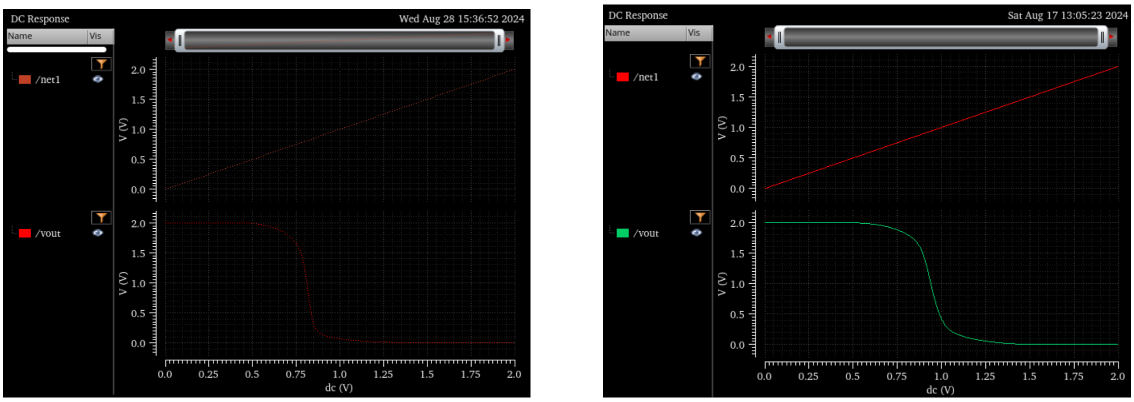


Fig. 7 DC Response waveform for gpdk180 (left) and gpdk45 (right)

DC Response Analysis

The DC response of the NOT gate, depicted in Fig. 7, reveals the relationship between the input voltage and the output voltage, providing a static view of the gate's transfer characteristics.

1. GPDK45: The DC response in GPDK45 shows a steep transition around the threshold voltage. This steep slope indicates a strong and swift switching capability, with the output voltage quickly reaching its maximum or minimum value as the input crosses the threshold. The sharpness of this transition suggests that GPDK45 has a smaller threshold voltage window, allowing for faster and more precise operation.
2. GPDK180: The DC response in GPDK180 exhibits a more gradual transition. The slope around the threshold voltage is less steep, indicating that the output changes more slowly in response to the input crossing the threshold. This can be beneficial in terms of noise margins, as the gate is less sensitive to small fluctuations in the input

signal. However, it also implies that the gate is slower to react, which aligns with the slower overall speed observed in the output waveform.

The comparison shows that GPDK45 offers a sharper and more defined switching behavior, ideal for applications requiring fast and accurate logic operations. In contrast, GPDK180 provides a more robust response, suitable for environments where stability and lower power consumption are prioritized.

Propagation Delay Comparison

Propagation delay is a critical parameter (Dhirubhai, L. M., & Pande, K. S. 2019, July) that measures the time taken for a signal to propagate through the NOT gate. It directly impacts the overall speed of a digital circuit.

1. GPDK45: The propagation delay in GPDK45 is significantly lower, with typical values around 10-15 ps (picoseconds). This short delay is a direct result of the smaller transistor sizes and faster switching times associated with the 45nm technology. The reduced capacitance and resistance in the interconnects further contribute to this low delay, making GPDK45 suitable for high-speed and high-frequency applications where timing is crucial.
2. GPDK180: In GPDK180, the propagation delay is higher, typically around 60-70 ps. The larger transistor sizes and increased parasitic capacitance and resistance in this 180nm technology result in slower signal propagation. While this longer delay makes GPDK180 less ideal for high-speed applications, it can be advantageous in low-power designs where slower operation is acceptable.

The substantial difference in propagation delays underscores the performance trade-offs between the two technologies. GPDK45 is clearly superior in terms of speed and is ideal for high-performance computing applications, whereas GPDK180, with its longer delay, might be more suitable for low-power, cost-sensitive, or noise-tolerant designs.

Conclusion of Results

The comparison between GPDK45 and GPDK180 technologies reveals a clear trade-off between speed, power consumption, and design complexity. GPDK45 excels in performance metrics, offering sharper output transitions, a steeper DC response, and significantly lower propagation delays, making it ideal for high-speed and high-performance applications. On the other hand, GPDK180, with its more gradual transitions and higher propagation delay, may be better suited for applications where power efficiency, robustness, and simpler design rules are more critical. These results highlight the importance of selecting the appropriate technology node based on the specific requirements of the application, balancing the need for speed against factors like power consumption, design complexity, and cost.

REFERENCES

Badiger, N. A., & Iyer, S. (2024). Design & Implementation of High Speed and Low Power PLL Using GPDK 45 nm Technology. Journal of The Institution of Engineers (India): Series B, 105(2), 239-249.

Dhirubhai, L. M., & Pande, K. S. (2019, July). Critical Path Delay Improvement in Logic Circuit Operated at Subthreshold Region. In 2019 International Conference on Communication and Electronics Systems (ICCES) (pp. 633-637). IEEE.

Dolan-Gavitt, B., Leek, T., Zhivich, M., Giffin, J., & Lee, W. (2011, May). Virtuoso: Narrowing the semantic gap in virtual machine introspection. In 2011 IEEE symposium on security and privacy (pp. 297-312). IEEE.

Gray, P. R., Hurst, P. J., Lewis, S. H., & Meyer, R. G. (2024). Analysis and design of analog integrated circuits. John Wiley & Sons.

Gupta, P., Ahluwalia, P., Sanwal, K., & Pande, P. (2015). Performance Comparison of Digital Gates using Cmos and Pass Transistor Logic using Cadence Virtuoso. Technology (length), 180, 180nm.

Gusmao, A., Canelas, A., Horta, N., Lourenco, N., & Martins, R. (2021, July). A Deep Learning Toolbox for Analog Integrated Circuit Placement. In SMACD/PRIME 2021; International Conference on SMACD and 16th Conference on PRIME (pp. 1-4). VDE.

Kajal, & Sharma, V. K. (2021). Design and Simulation for NBTI Aware Logic Gates. Wireless Personal Communications, 120(2), 1525-1542.

Liu, Y. (2021, January). Advantages of CMOS technology in very large scale integrated circuits. In Proceedings of the 2021 2nd International Conference on Artificial Intelligence in Electronics Engineering (pp. 82-88).

Maity, I. (2024). Cadence Virtuoso based circuit simulation of universal logic gates: A board tutorial.

Mamo, T. M., & Zhang, N. (2022, April). VLSI Design, Verification and Fabrication of an Arithmetic Logic Unit (ALU) Using the Cadence Virtuoso: A Case Study. In 2022 Spring ASEE Middle Atlantic Section Conference, Newark. ASEE.

Mirhoseini, A., Goldie, A., Yazgan, M., Jiang, J. W., Songhori, E., Wang, S., ... & Dean, J. (2021). A graph placement methodology for fast chip design. Nature, 594(7862), 207-212.

Nidagundi, J. C. (2021). Design of I/O Interface for DDR2 SDRAM Transmitter Using gpdk 180 nm Technology. In Advanced Computing: 10th International Conference, IACC 2020, Panaji, Goa, India, December 5–6, 2020, Revised Selected Papers, Part II 10 (pp. 215-227). Springer Singapore.

Walter, J. G., Alwis, L. S., Roth, B., & Bremer, K. (2020). All-optical planar polymer waveguide-based biosensor chip designed for smartphone-assisted detection of vitamin D. Sensors, 20(23), 6771.

Wu, C. J., Liu, C. P., & Ouyang, Z. (2012). Compact and low-power optical logic NOT gate based on photonic crystal waveguides without optical amplifiers and nonlinear materials. Applied optics, 51(5), 680-685.

Yi, M. A. S., Hussin, R., Ahmad, N., & Rokhani, F. Z. (2021, September). Area optimization of comparator layout design by using Cadence Virtuoso tools in 45 nanometer process technology. In 2021 IEEE International Conference on Sensors and Nanotechnology (SENNANO) (pp. 134-137). IEEE.