*Volume 1 (Issue 3: July- October, 2025): Pages **01-13*** | https://www.swamivivekanandauniversity.ac.in/jrtee/
Published on November 16, 2025

ISSN: 3049-382X (Online)

Journal of Recent Trends of Electrical Engineering

contents available at: *https://www.swamivivekanandauniversity.ac.in/jrtee/*

EV Battery Charging System and Impact of Uncoordinated Charging on Distribution Network

Promit Kumar Saha[1], Nitai Pal[2], Faizan A. Khan[3] , Aftab Alam[4]
[1]*Research Scholar, Electrical Engineering, IIT (ISM) Dhanbad, India*
[2] *Professor, Electrical Engineering, IIT (ISM) Dhanbad, India*
[3]*Assistant Professor, Electrical Engineering, BIET, Lucknow, UP, India*
[4]*Assistant Professor, Electrical and Electronics Engineering, BIT MESRA, India*

Abstract

EV Charging system topologies and their control are vital in electric cars. This paper presents a Simulation and Analysis of controlled charging (Constant Current Constant Voltage, CC/CV) of an On-board unidirectional full-bridge series resonant charger (Level 2) along with Load flow analysis of Uncoordinated Charging at different penetration levels of EVs. The EV charger control strategies & analysis of Load flow in the IEEE-15 Bus Radial Distribution network have been performed in MATLAB-SIMULINK R2017 (a). Uncoordinated loading of vehicles on the local grid can cause various severe distribution problems. The optimal or Coordinated Charging scheme of EVs is based on the maximization of the load factor and the minimization of power losses of the grid.

Keywords

CCCV Control, Battery charging strategies, charging topology, DSM-PI Control, coordinated charging scheme, Load flow.

1.Introduction

Worldwide, government agencies and corporations are continually striving to reduce carbon emissions associated with the combustion of fossil fuels. As per data provided by the Energy Department, diesel internal combustion engines (ICEs) account for the major part of global non-renewable energy fuel consumption. ICEs perform inefficiently and emit harmful oxides of carbon, nitrogen, and sulfur [1], [2]. In contrast, Plug-in Electric Vehicles (PEVs) and Electric Vehicles (EVs) offer significantly greater productivity and profitability advantages [3]. For the purposes of this paper, all types of electric vehicles, including EVs and PHEVs, are collectively referred to as EVs.

The Battery Energy Storage System is a crucial component in an EV, constituting about one-third of the vehicle's total cost. Batteries typically have a power range between 10 kWh and 50 kWh. As per SAE charging standards, there are three levels of EV charging. This paper models a Level 2 charger rated at 240 V (single-phase)/60 A/15 kW. The Constant Current Constant Voltage (CCCV) control strategy combines both CC and CV charging methods to enhance system reliability, battery longevity, charging speed, and overall efficiency [4], [5].

Studies in [6] and [7] have examined the PHEVs loading effect on the distribution grid. Initially, they showed the adverse effects of uncoordinated PHEV charging, highlighting issues like node voltage deviation and increased feeder power loss. These findings were based on a 4 kW charger connected to various nodes. In [8], the authors conducted a case study on the placement of charging stations in Berlin. Their analysis concluded that uncoordinated charging at these stations leads to considerable line power losses and voltage sags.

A hierarchical coordination model was proposed in [9] to efficiently regulate reactive active and power flows of spatially distributed EVs while considering the constraints of the distribution grid. This model involves detailed mathematical calculations that can enhance EV charging and grid operations processes. The authors divided the computations into two distinct models: a comprehensive optimal power flow model at the distribution grid level and a detailed optimal EV charging model proposed to deliver support to the grid reactive power zone.

In [10], EVs are examined in both the first and fourth quadrants, indicating their capability to either inject or consume apparent power during the charging and discharging processes. The authors introduced a three-phase Distribution Optimal Power Flow (DOPF) model designed and tested for unbalanced distribution systems. This versatile DOPF model integrates single-phase, two-phase, and three-phase representations of feeders, transformers, switches, and Load Tap Changers (LTCs) within an optimization framework. The DOPF model incorporates the ZIP load model to represent regular, non-flexible loads within the system, as described in [11] and [12]. In [13] and [14], the authors experimentally derived the ZIP coefficients to accurately model all types of loads under changes in voltage conditions.

The primary goal of this paper is to address the issues related to uncoordinated EV loading on local distribution networks without necessitating significant upgrades to the existing infrastructure. The paper is structured as follows: Section II analyzes the onboard unidirectional charger topology and its controls. Section III presents a load flow analysis at various penetration levels for uncoordinated charging. Coordinated charging strategies are discussed in Section IV. Section V showcases the results, followed by the conclusion and references.

2. TOPOLOGY DESIGN AND CONTROL

Unidirectional charging reduces the requirements of hardware, eases the interconnection difficulties & helps to slow down battery health depletion (SOH). Unidirectional Chargers (Level 2) are the most efficient in terms of weight, capacity, losses & charging speed. Level 3 charging in suburban areas is seldom possible owing to the high voltage & current specifications as well as running costs [15]. The on-board unidirectional full-bridge series resonant charger topology implemented in this paper consists of two diode bridge AC/DC converters, a boost converter circuit (PFC, power factor correction), an inverter circuit, a series resonant converter for less distorted output [16] along with a high-frequency transformer for conductive isolation as shown in Figure.1.

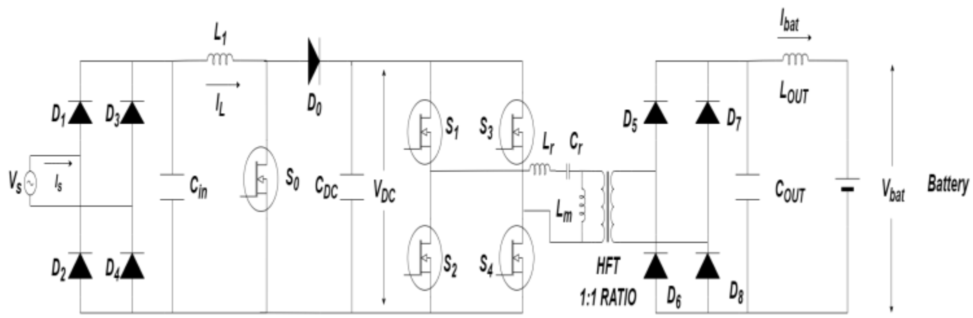

Fig.1. Unidirectional full bridge series resonant circuit topology as On-board Circuit

A. PFC Control and Simulation

The PFC controller aims to maintain a power factor near unity by aligning the phase of the input current with that of the input voltage on the source AC side, thereby minimizing the reactive power burden on the grid [17]. Figures 2 and 3 illustrate the PFC control block diagram and the corresponding simulation results.

Fig.2 Block Diagram of PFC control of boost converter circuit

B. CCCV Controller Design

The CC strategy is normally used to resist overcurrent in the initial phase of charging. The CV strategy is used in a later stage. The charging of the battery is primarily performed in CC mode, where the charging output current is retained as constant and the charging output voltage increases. When the voltage reaches a predetermined value, the control will shift to CV mode. When the output current decreases to the cut-off point, the process of charging stops. The selection between CC & CV strategies is made by using a CV selector switch (as shown in figure 4), which constantly compares battery voltage to a preset voltage (here it is 270V).

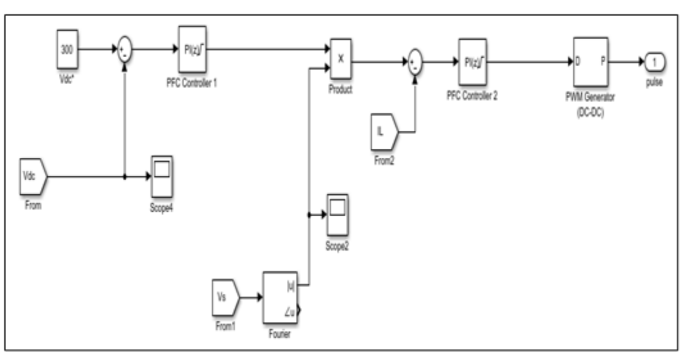

Fig.3 Simulation of PFC control using boost converter circuit

This paper compares two control methods: Conventional PI control and DSM-PI control. The DSM-PI control is a hybrid technique that integrates a standard PI controller with Sliding Mode (SM) control to regulate the DC-link voltage. In this approach, the SM scheme dynamically adjusts the PI controller's gains based on the error in the control loop and its derivative [18]. The proposed topology of the CCCV control strategy is presented in Figure 5.

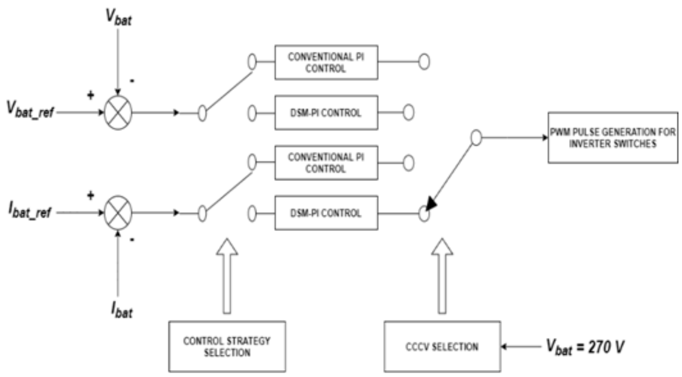

Fig.4. Control strategy & CCCV Selector

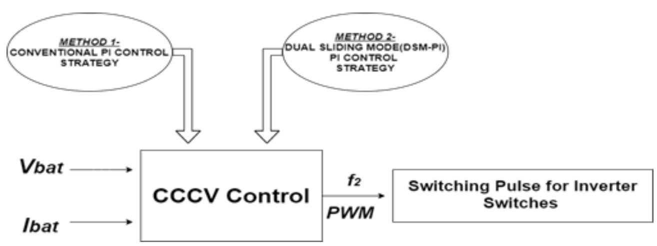

Fig.5 Block Diagram of CCCV Control strategy

Based on stability constraints, the gains for the controller can be evaluated using the switching equations given below [18].

$$kp\sim=[(1+sgnm(\sigma))kp+ -(1-sgnm(\sigma))kp-]+ kpav \qquad (1)$$

$$ki\sim =[(1+sgnm(\sigma))ki+-(1-sgnm(\sigma))ki-] + kiav \qquad (2)$$

where kp~, ki~ , kp+ , ki+ ,kp- , ki -, kpav and kiav are positive constants calculated as a function of the intended response of the proposed system. (These gains can be attained using the standard PI tuning method). Some constants like C, ƛ, and µt are directly taken into this paper from the reference paper [18]. Parameters of DSM-PI 1,2 Controller are shown in below Table I & II.

TABLE I. PARAMETERS FOR DSM-PI 1 CONTROLLER

$k_p^+ = 0.1$	$k_p^- = 0.2$	$k_p^{av} = 20$
$k_i^+ = 0.2$	$k_i^- = 0.1$	$k_i^{av} = 1$
C = 100	$\lambda = 500$	$\mu_t = 0.98$

TABLE II. PARAMETERS FOR DSM-PI 2 CONTROLLER

$k_p^+ = 0.000033$	$k_p^- = 0.000022$	$k_p^{av} = 0.0002$
$k_i^+ = 0.00215$	$k_i^- = 0.00088$	$k_i^{av} = 0.001$
C = 100	$\lambda = 500$	$\mu_t = 0.98$

Battery modeling has been done based on the battery discharge curve data given in Table III & Figure 6. Parameters for Charger topology & Controller design are given in Tables IV & V.

TABLE III. PARAMETERS FOR BATTERY MODELLING

Parameters	**Values**
Nominal Voltage	*250 V*
Rated Capacity	*40 Ah*
Constant Voltage, E_0	*271.0898 V*
Polarization resistance, K	*0.0468* Ah^{-1}
Internal resistance, R	*0.0625 Ω*
Exponential zone amplitude, A	*20.994 V*
Exponential zone capacity, B	*1.526* Ah^{-1}

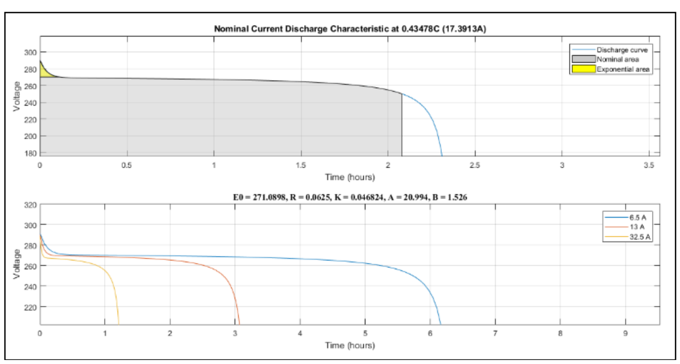

Fig.6. Battery parameters based on discharge curve

TABLE IV. PARAMETERS FOR CHARGING CIRCUIT TOPOLOGY

Parameters	**Values**	**Parameters**	**Values**
Level 2 Rating	240 V,50 Hz	L_m	20 mH
Battery Rating	250 V,40 Ah	C_{out}	1 mF
L_1	100 mH	L_{out}	10 mH
C_{DC}	9.5 Mf	f_1 , f_2	2 KHz,500 Hz
L_r	3 Mh	C_{in}	20 mF
C_r	30 µF	V_{dc_ref}	300 V

TABLE V. PARAMETERS FOR CONTROLLER DESIGN

Parameters	**Values**
PFC Controller 1 coefficient, k_p	0.001
PFC Controller 1 coefficient, k_i	0.1
PFC Controller 2 coefficient, k_p	0.003
PFC Controller 2 coefficient, k_i	0.3
Current Controller coefficient, k_p	0.0015
Current Controller coefficient, k_i	0.15
Voltage Controller coefficient, k_p	20
Voltage Controller coefficient, k_i	2

MATLAB Simulation

All the following simulation works have been performed in MATLAB-SIMULINK R2017 (a) & shown in Figures 7-9.

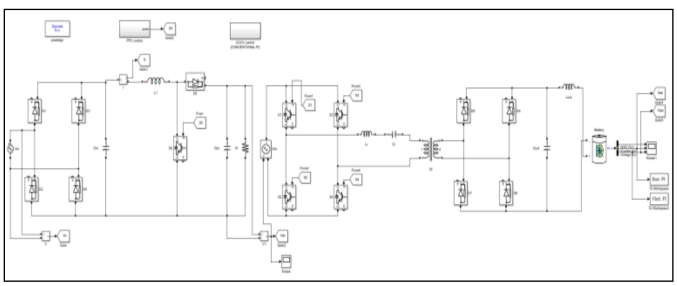

Fig.7. Main Topology Simulation

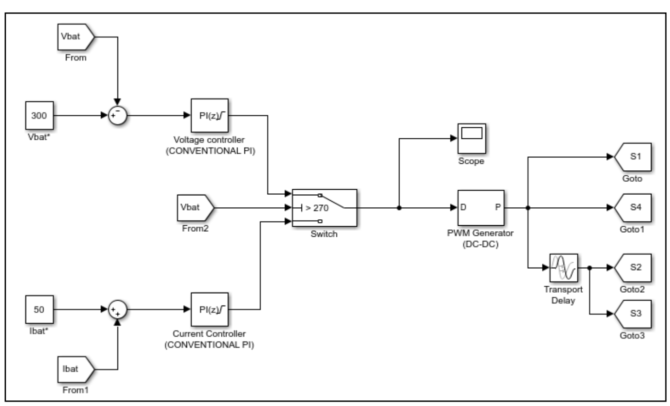

Fig.8. CCCV Control (Conventional PI)

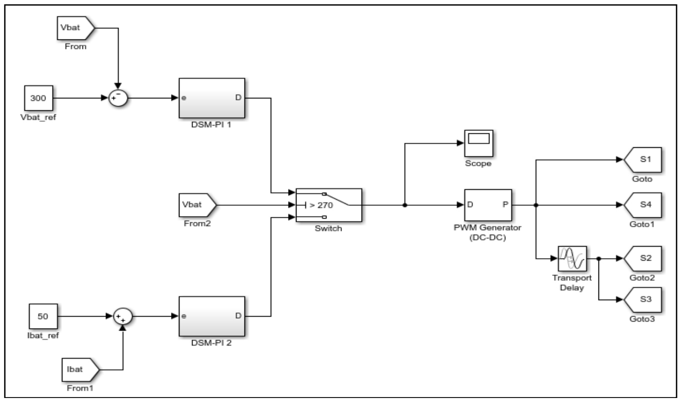

Fig.9. CCCV Control (DSM-PI)

UNCOORDINATED CHARGING

Uncoordinated Charging indicates that electric vehicle batteries are getting charged randomly to any arbitrary node of the distribution system as per the owners' interest. The primary motive of EV owners is to minimize the cost of charging. There is no communication between Grid operators & customers regarding the EV load scheduling to optimize grid utilization [19], [20].

EV Charger Modeling

To conduct the Load flow of uncoordinated charging, EV battery (E-Rickshaw) charger socket has been modeled as constant PQ load under steady-state condition. It is based on the apparent power consumed by charger from the grid as shown in the Figure.9.

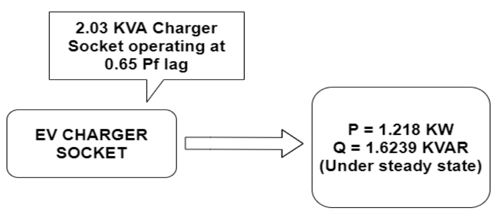

Fig.10. PQ load modeling of EV charger socket

Load Flow & Simulation of Uncoordinated Charging

Firstly, An IEEE 15 Bus Radial Distribution Network (RDN) has been modeled as per the standard line and load data. A SIMULINK model of IEEE 15 Bus RDN with 0% penetration level (EV free) has been shown in Figure.11. Thereafter, EV loads have been planted at different random nodes of the system according to penetration level (0%, 20%, and 40%) of EVs. Penetration here stands for the no. of nodes with EV loads connected. In this paper, 400 such vehicles have been planted at random nodes out of a total of 15 nodes. A simulation of a 40% penetration level i.e. 6 nodes out of 15 nodes with EV loads on, has been shown in Figure.12.

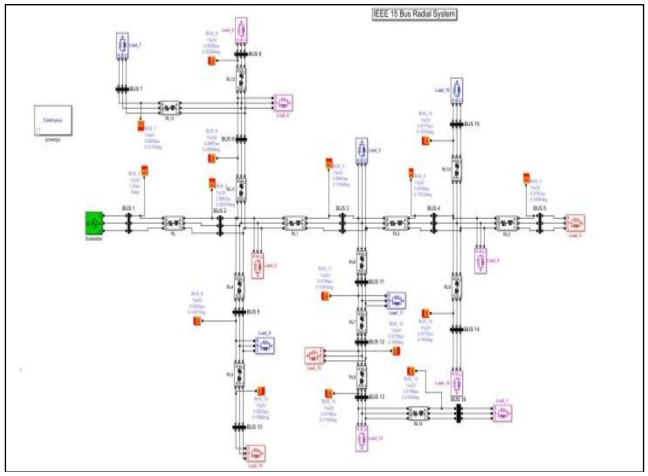

Fig.11. IEEE 15 Bus RDN with 0% penetration level (EV free loading)

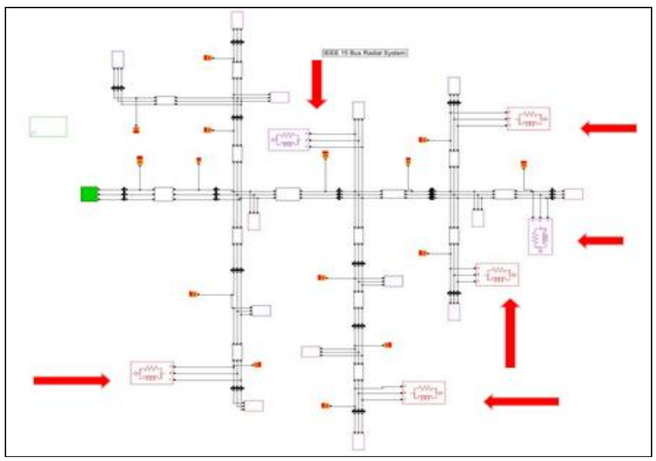

Fig.12. IEEE 15 Bus RDN with 40 % penetration level

COORDINATED CHARGING

There is bi-directional communication between individual EV owner & Grid operator, which can be performed using a smart metering system [21]. Grid operator collects information like SOCs, degree of urgency to charge the vehicle, owner's commitment, etc with the help of EV aggregators. The operator then generates an optimal charging schedule for a group of EVs connected to different area buses according to voltage level analysis of each bus. Some of the EV groups might be asked to delay the charging, seeing the criticalness of their bus voltage to minimize the line losses & grid operational cost [22].

An algorithm has been proposed in this paper shown in Figure.13.The Proposed Algorithm can be extended for further analysis like development of a novel mathematical objective function, comparison with uncoordinated charging results etc.

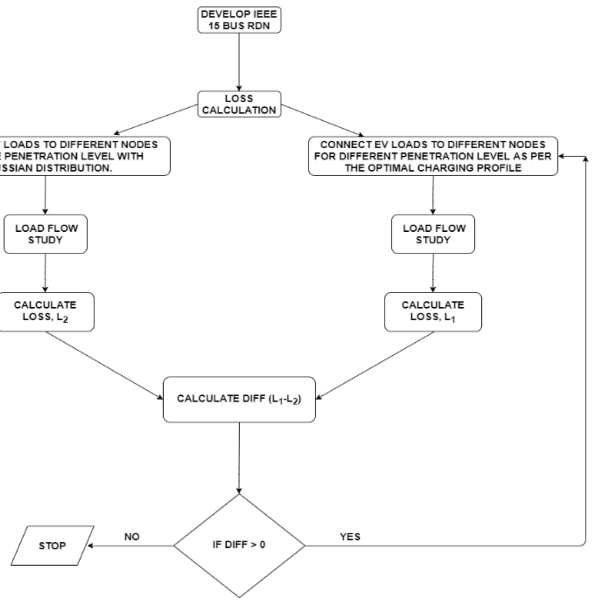

Fig.13. Optimal charging algorithm

RESULTS

The output of PFC Boost Converter is taken to be the same for both control strategies as shown in Figure.13.To show the switching between CC and CV in the same Figure, Simulation should be run for 2500 seconds from 0% to 100 % SOC, which is not feasible in MATLAB-SIMULINK R2017 (a). It is because of the fact i.e. Battery Voltage increases with an increase in SOC %.To solve this issue, CC &CV mode has been shown separately at 5 % & 70 % initial battery SOC in Figures.14-16. Battery Voltages & Charging Currents are compared using both control strategies & transient behaviour of both the controllers is highlighted in elliptical notation as shown in Figures.17-18.Further, Load flow studies like Voltage variation & Line power loss % for different penetration levels have been shown in Figures.19-21.

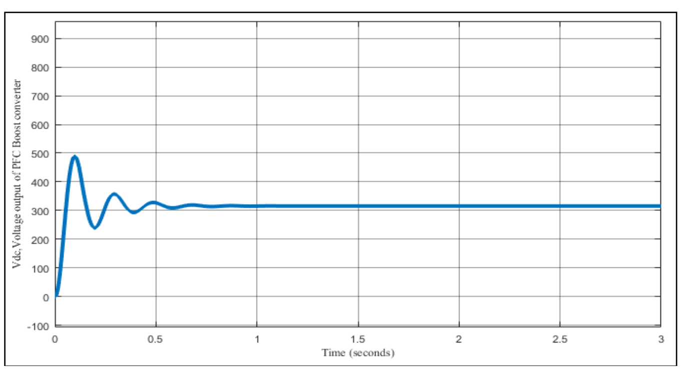

Fig.13. Output of PFC Boost Converter

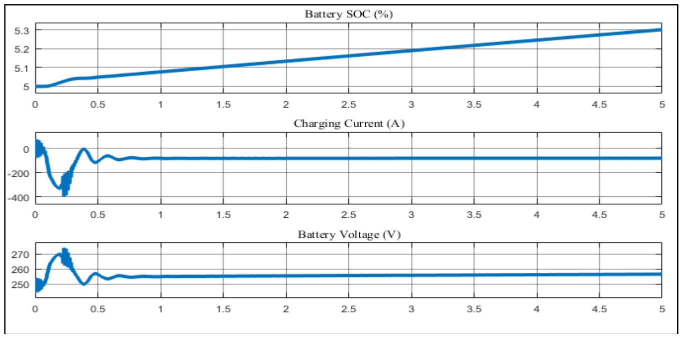

Fig.14. Battery Parameters in CC mode (CONVENTIONAL PI CONTROL)

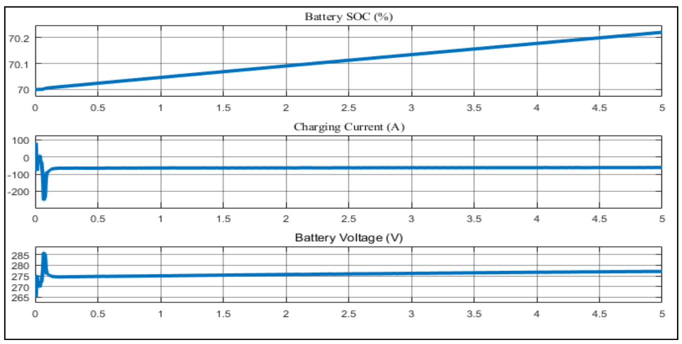

Fig.15. Battery Parameters in CV mode (CONVENTIONAL PI CONTROL)

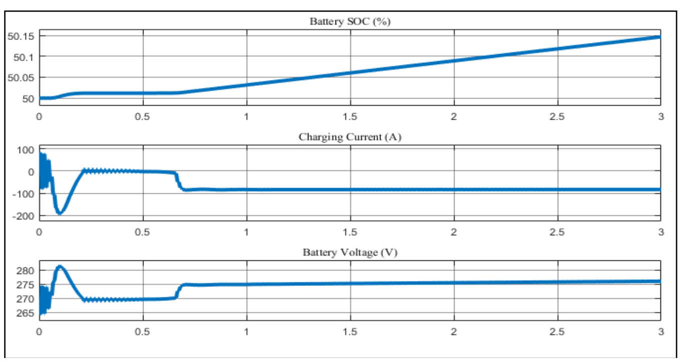

Fig.16. Battery Parameters in CV mode (DSM-PI CONTROL)

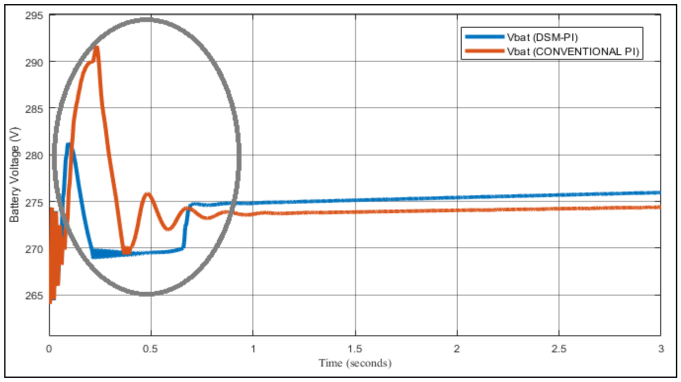

Fig.17. Comparison of Battery Voltages

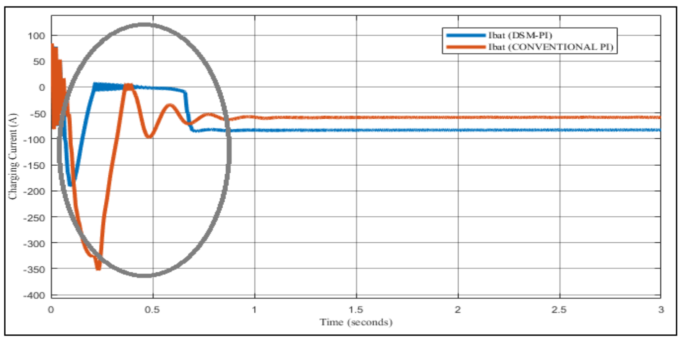

Fig.18. Comparison of Charging Currents

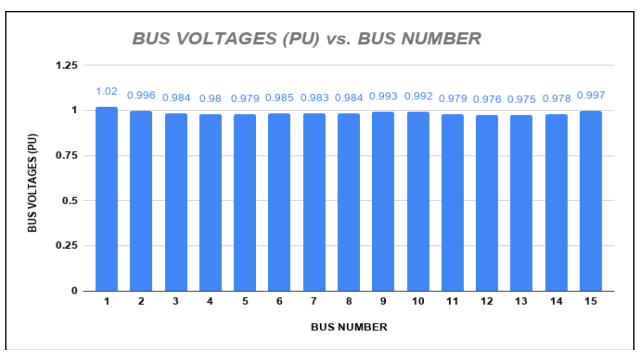

Figure.19. Bus Voltages at 0% Penetration

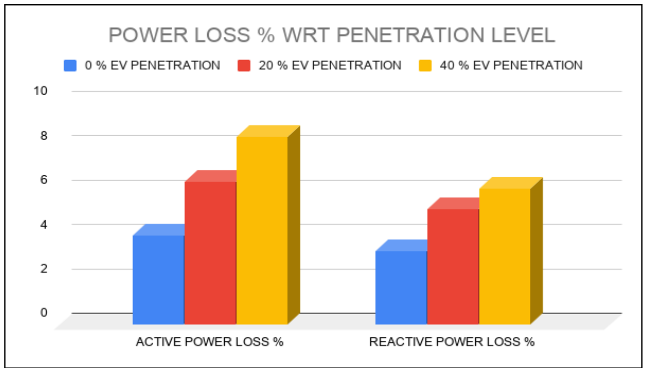

Fig.20. Line Power loss % at different penetration level

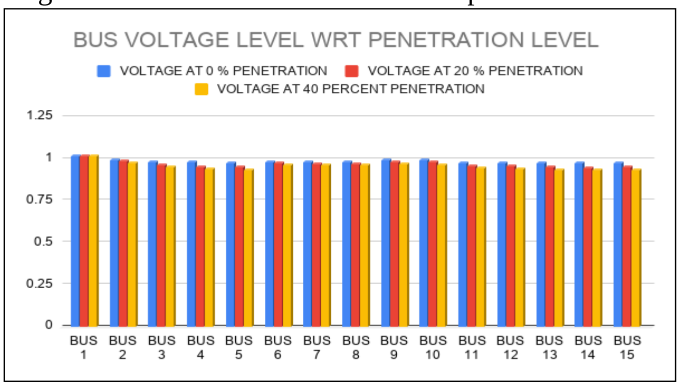

Fig.21. Bus Voltage level at different penetration level

CONCLUSION

Level 2 unidirectional topology (CCCV) with DSM-PI Control methodology gives better results as compared to conventional PI controlled charger in terms of speed of charge (due to high charging current) & transient behaviour. As the penetration level increases, Line power loss increases to an avoidable mark which may cause problems such as Transformer overloading, excessive voltage drop at far end nodes, Line overloading, increased reactive power burden on generator, etc.

REFERENCES

[1] "Review of the impact of vehicle-to-grid technologies on distribution systems and utility interfaces," IEEE Transactions on Power Electronics, vol. 28, no. 12, pp. 5673–5689, Dec 2013.

[2] M. Yilmaz and P. T. Krein, "Review of battery charger topologies, Charging power levels, and infrastructure for plug-in electric and hybrid vehicles," IEEE Transactions on Power Electronics, vol. 28, no. 5,pp.2151–2169, May 2013.

[3] S. G. Wirasingha and A. Emadi, "Pihef: Plug-in hybrid electric factor,"in 2009 IEEE Vehicle Power and Propulsion Conference, Sept 2009, pp.661–668.

[4] L. Bao, L. Fan and Z. Miao, "Real-Time Simulation of Electric Vehicle Battery Charging Systems," *2018 North American Power Symposium (NAPS)*, Fargo, ND, 2018, pp. 1-6, doi: 10.1109/NAPS.2018.8600543.

[5] A. Tazay and Z. Miao, "Control of a Three-Phase Hybrid Converter for a PV Charging Station," in *IEEE Transactions on Energy Conversion*, vol. 33, no. 3, pp. 1002-1014, Sept. 2018, doi: 10.1109/TEC.2018.2812181.

[6] K. Clement-Nyns, E. Haesen and J. Driesen, "The Impact of Charging Plug-In Hybrid Electric Vehicles on a Residential Distribution Grid," in *IEEE Transactions on Power Systems*, vol. 25, no. 1, pp. 371-380, Feb. 2010, doi: 10.1109/TPWRS.2009.2036481.

[7] K. Clement, E. Haesen and J. Driesen, "Coordinated charging of multiple plug-in hybrid electric vehicles in residential distribution grids," *2009 IEEE/PES Power Systems Conference and Exposition*, Seattle, WA, 2009, pp. 1-7, doi: 10.1109/PSCE.2009.4839973.

[8] M.Draz, M. Voß, D. Freund and S. Albayrak, "The Impact of Electric Vehicles on Low Voltage Grids: A Case Study of Berlin," *2018 Power Systems Computation Conference (PSCC)*, Dublin, 2018, pp. 1-7.

[9] J. Wang, G. R. Bharati, S. Paudyal, O. Ceylan, B. P. Bhattarai and K. S. Myers, "Coordinated Electric Vehicle Charging With Reactive Power Support to Distribution Grids," in *IEEE Transactions on Industrial Informatics*, vol. 15, no. 1, pp. 54-63, Jan. 2019.

[10] M. C. Kisacikoglu, B. Ozpineci and L. M. Tolbert, "EV/PHEV Bidirectional Charger Assessment for V2G Reactive Power Operation," in *IEEE Transactions on Power Electronics*, vol. 28, no. 12, pp. 5717-5727, Dec. 2013.

[11] M. Kesler, M. C. Kisacikoglu and L. M. Tolbert, "Vehicle-to-Grid Reactive Power Operation Using Plug-In Electric Vehicle Bidirectional Offboard Charger," in *IEEE Transactions on Industrial Electronics*, vol. 61, no. 12, pp. 6778-6784, Dec. 2014.

[12] S.Paudyal, C. A. Canizares and K. Bhattacharya, "Optimal Operation of Distribution Feeders in Smart Grids," in *IEEE Transactions on Industrial Electronics*, vol. 58, no. 10, pp. 4495-4503, Oct. 2011.

[13] S.A. Kalinowsky and M. N. Forte, "Steady State Load-Voltage Characteristic Field Tests at Area Substations and Fluorescent Lighting Component Characteristics," in *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-100, no. 6, pp. 3087-3094, June 1981.

[14] A. Bokhari *et al*., "Experimental Determination of the ZIP Coefficients for Modern Residential, Commercial, and Industrial Loads," in *IEEE Transactions on Power Delivery*, vol. 29, no. 3, pp. 1372-1381, June 2014.

[15] M. Yilmaz and P. T. Krein, "Review of Battery Charger Topologies, Charging Power Levels, and Infrastructure for Plug-In Electric and Hybrid Vehicles," in IEEE Transactions on Power Electronics, vol. 28, no. 5, pp. 2151-2169, May 2013, doi: 10.1109/TPEL.2012.2212917.

[16] J. Wu, Y. Li, X. Sun, and F. Liu, “A new dual-bridge series resonant dc/dc converter with dual tank,” IEEE Transactions on Power Electronics, vol. 33, no. 5, pp. 3884–3897, May 2018.

[17] C. H. Dharmakeerthi, N. Mithulananthan, and T. K. Saha, “Modeling and planning of ev fast charging station in power grid,” in 2012 IEEE Power and Energy Society General Meeting, July 2012, pp. 1–8.

[18] R. L. d. A. Ribeiro, T. d. O. A. Rocha, R. M. de Sousa, E. C. dos Santos and A. M. N. Lima, "A Robust DC-Link Voltage Control Strategy to Enhance the Performance of Shunt Active Power Filters Without Harmonic Detection Schemes," in *IEEE Transactions on Industrial Electronics*, vol. 62, no. 2, pp. 803-813, Feb. 2015, doi: 10.1109/TIE.2014.2345329.

[19] S. M. Mousavi Agah and A. Abbasi, "The impact of charging plug-in hybrid electric vehicles on residential distribution transformers," *Iranian Conference on Smart Grids*, Tehran, 2012, pp. 1-5.

[20] S. Paudyal and S. Dahal, "Impact of Plug-in Hybrid Electric Vehicles and their optimal deployment in Smart Grids," *AUPEC 2011*, Brisbane, QLD, 2011, pp. 1-6.

[21] I. M. A. Nrartha, A. B. Muljono, I. M. Ginarsa, S. M. Al Sasongko and I. B. F. Citarsa, "Smart Energy Meter for Electric Vehicle Based on Bluetooth and GSM Technology," *2018 International Conference on Smart Green Technology in Electrical and Information Systems (ICSGTEIS)*, Bali, Indonesia, 2018, pp. 7-12, doi: 10.1109/ICSGTEIS.2018.8709139.

[22] X. Rong *et al*., "Coordinated charging strategy of electric vehicle charging station based on combination of linear power flow and genetic algorithm," *2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC)*, Xi'an, 2016, pp. 1772-1776, doi: 10.1109/APPEEC.2016.7779793.