International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 7, July 2026

Design and Simulation of Fuzzy Logic Controlled Bidirectional Smart Grid and Electric Vehicle Integration System

Om Prakash Jhariya[1], Durgesh Vishwakarma[2]
M.Tech. Scholar, Department of Electrical &Electronics Engg. REC Bhopal (India)
Assistant Professor, Department of Electrical &Electronics Engg. REC Bhopal (India)

Abstract— This research paper primarily focuses on the integration of photovoltaic (PV) smart grids (SG) and electric vehicles (EVs) with two-way power flow capabilities. This includes charging, discharging, and enhancing power quality using power converters. Given the rising energy demand due to rapid population growth, modernizing the power grid to improve power quality is essential. This modernization allows the energy generated by solar PV systems to be transmitted and stored as excess power in batteries for use during peak load demands. Electric vehicle batteries can be charged during low-demand periods and discharged during peak demand. This dual function enables EVs to serve both as loads and as energy suppliers to the smart grid. Simulation results illustrate the operation of the smart grid-to-vehicle (G2V) system, highlighting improvements in factors such as power factor, power regulation, and harmonic elimination. These enhancements are achieved by constructing a power electronic network capable of bidirectional power flow and balancing the grid, using MATLAB/Simulink software. Additionally, the G2V controller has been enhanced with a fuzzy logic controller to achieve better stability in the battery current. The implementation of fuzzy logic control has notably reduced current ripple, peak overshoot, and settling time. Furthermore, the paper thoroughly examines improvements in the power quality of the integrated system, focusing on power compensation, voltage regulation, and harmonic mitigation.

Keywords— Grid to Vehicle (G2V), Fuzzy Logic Controller, Photovoltaic (PV), Smart Grids (SG)

I. INTRODUCTION

The integration of renewable energy sources, particularly solar energy, into the power grid has gained significant momentum in recent years due to the global shift toward sustainable energy solutions. Solar photovoltaic (PV) systems play a crucial role in addressing the growing energy demand while reducing carbon emissions. However, the increasing penetration of solar PV systems into the grid introduces new challenges in maintaining power quality, stability, and reliability [1].

Normally, foothold batteries are utilized in electric vehicles which can deal with high power and energy inside a restricted space and weight. As a result, extensive research is being conducted to advance EV-friendly battery technology. In the past, only electric vehicles made use of lead acid batteries. In any case, nickel batteries have the issue of high self-release and intensity age at high temperatures [2, 3]. Due to their small size, light weight, and high-power density, lithium batteries are currently preferred. It beats the issues of low unambiguous energy, poor temperature attributes and compound spillage. Its wide temperature range, long life cycle, low self-discharge rate, and fast charging capability also increase its use in the electric vehicle industry [4]. The most frequently used lithium batteries are lithium titanate and lithium ferro-phosphate. Lithium ferro-phosphate battery has unrivaled warm strength in the completely energized condition and it has generally safe when coincidentally over charged. Lithium titanate batteries can be recharged quickly and operate at a wide temperature range [5, 6].

The use of electric vehicles is limited because of the difficulties associated with charging the batteries, as well as the cost, life cycle, and cost. On-board and off-board chargers are the two main types of EV battery chargers. An on-board charger is inside the vehicle, whereas an off-board charger is only installed at the fixed location. The on-board charger is constrained by a number of factors, including weight, space, cost, and size [6, 7]. The motor winding itself can be used as the filter inductors or isolated transformer in order to circumvent these limitations by integrating this charger with the EV's motor drives. There are two types of charging systems: conductive and inductive. The EV connector and charger inlet are in direct contact in the conductive system. In contrast, power is transferred magnetically in an inductive system.

One emerging area in this context is the bidirectional grid-to-vehicle (G2V) and vehicle-to-grid (V2G) integration. Bidirectional charging systems enable electric vehicles (EVs) to act not only as consumers but also as distributed energy resources, supplying energy back to the grid during peak demand periods. While this integration promises enhanced energy efficiency and grid flexibility, it also brings challenges such as voltage fluctuations, harmonic distortion, and unbalanced load conditions, which compromise overall power quality [8].

To address these challenges, advanced control strategies are essential. Among these, fuzzy logic controllers (FLCs) have proven to be highly effective due to their ability to handle nonlinear, uncertain, and complex systems without requiring precise mathematical models. Fuzzy logic provides a rule-based approach to regulate system parameters and ensure power quality enhancement in solar PV-based G2V systems.

International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 7, July 2026

II. PROPOSED METHODOLOGY

A comprehensive appraisal of the writing is given the objective of diminishing the quantity of gadgets expected to help an expanded number of result levels. The thesis's objectives and structure are discussed in depth in this section. These days, interests in new sustainable and economical energy areas are quickly done to lessen CO_2 outflows and address an Earth-wide temperature boost brought about by the utilization of petroleum products.
Solar photovoltaic and wind energy-based power generation systems are largely due to developments in power electronics. in order to connect these sources to either local loads or the distribution grid. Figure 1 depicts the proposed work's fundamental application.

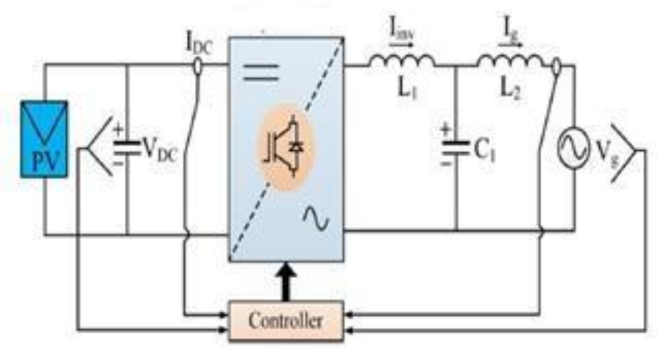

Figure 1: Proposed Work Fundamental Application

2.1 A Fuzzy Logic Controller (FLC) with a PWM (Pulse Width Modulation)

Generator is a widely used control approach in power electronics and renewable energy systems. It combines the decision-making flexibility of fuzzy logic with the precision of PWM signal generation, enabling efficient control of power converters and related components in complex systems.

Fuzzy Logic Controller (FLC):

- **Inputs**: The FLC typically takes in two or more inputs such as error (e) and change in error (Δe), representing the deviation from the desired state and its rate of change, respectively.
- **Rule Base**: A set of "if-then" rules forms the core of the FLC, mapping input conditions to control actions. For example:
  If e is large and positive **and** Δe is small, **then** increase output significantly.
- **Fuzzification**: Converts precise input values into fuzzy sets (linguistic variables such as "low," "medium," "high").
- **Inference Mechanism**: Applies the rule base to compute fuzzy outputs based on the input conditions.
- **Defuzzification**: Converts the fuzzy outputs back into crisp values for system control.

PWM Generator:

- **Purpose**: Converts the continuous control signal from the FLC into discrete pulses that drive switching devices such as IGBTs or MOSFETs in inverters, converters, or other power electronic systems.
- **Pulse Generation**: The PWM generator compares the FLC output signal with a high-frequency carrier waveform (e.g., a triangular wave). When the FLC output exceeds the carrier signal, a pulse is generated. The width of the pulse is proportional to the magnitude of the FLC output, thereby controlling the energy transfer.
- **Switching Control**: These pulses directly control the switching of power devices, enabling dynamic regulation of output voltage, current, or power.

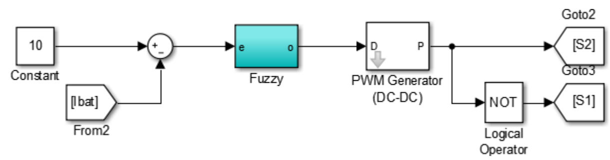

Fig. 2Fuzzy Logic Controller with PWM Generator

III. RESULT AND DISCUSSION

The transition to sustainable energy systems has accelerated the adoption of electric vehicles (EVs) as a viable alternative to traditional fossil-fuel-based transportation. The integration of EVs with the power grid, known as Grid-to-Vehicle (G2V) systems, has emerged as a crucial component in this transformation. G2V systems enable the efficient transfer of electricity from the grid to EV batteries, supporting the dual objectives of meeting transportation energy demands and optimizing grid operations.
As the penetration of EVs continues to rise, their charging infrastructure introduces both opportunities and challenges for power grid stability and efficiency. A G2V system facilitates the seamless charging of EVs, leveraging smart grid technologies to ensure efficient energy management. However, challenges such as grid overloading, voltage fluctuations, and harmonic distortion must be addressed to prevent adverse impacts on power quality.
To overcome these challenges, advanced control mechanisms and intelligent energy management strategies are essential. Fuzzy logic controllers (FLCs) and other optimization techniques have proven effective in addressing the dynamic and nonlinear nature of G2V systems. By managing real-time charging demands, minimizing grid disturbances, and integrating renewable energy sources, G2V systems can contribute to building a resilient and sustainable energy ecosystem.
This research explores the design and optimization of Grid-to-Vehicle integration systems, focusing on their role in improving power quality, enhancing grid efficiency, and enabling the widespread adoption of EVs. By examining the interplay between advanced control systems and power electronics, this study aims to propose innovative solutions

that align with the goals of smart grids and sustainable transportation.

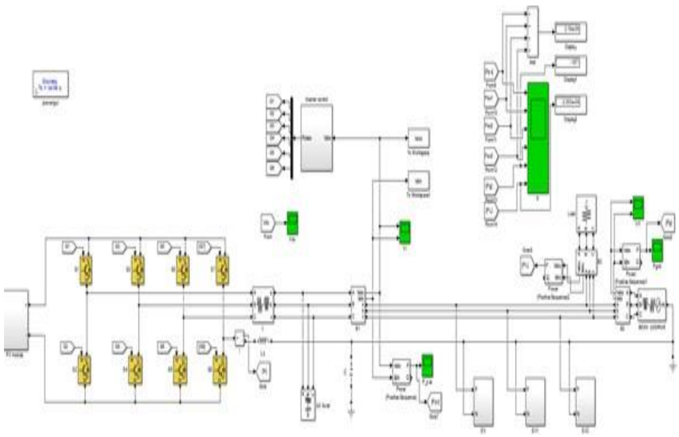

Figure 3: Simulation Model of Smart Grid and EV integration system with controllers and loads

The Electric Vehicle (EV) Circuit Structure with MOSFET Switch is commonly used in the power electronics system of EVs, particularly in battery charging circuits, inverters, and motor controllers. MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) are preferred in these applications due to their high efficiency, fast switching capabilities, and ability to handle high currents and voltages.

- Serves as the primary switching device for power conversion.
- Operates in various configurations, such as high-side, low-side, or as part of an H-bridge.
- Controls the flow of current between the battery, inverter, and load (e.g., motor).

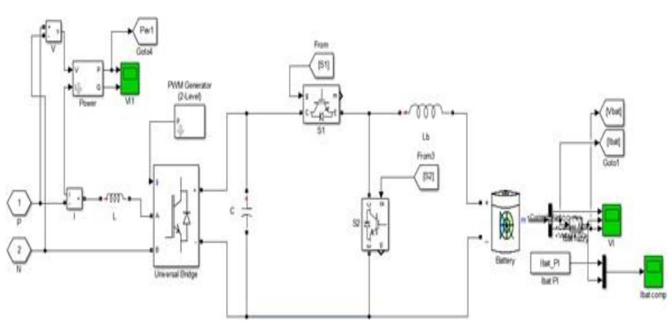

Figure 4: EV circuit structure with MOSFET Switch

The above figure 4 are the modeling of the complete proposed system with PV array module connected to grid along with EV charging units. All the devices are connected to a common point named as Point of Common Coupling (PCC). The characteristics of the PV array for the given solar irradiation can be observed in figure 5.

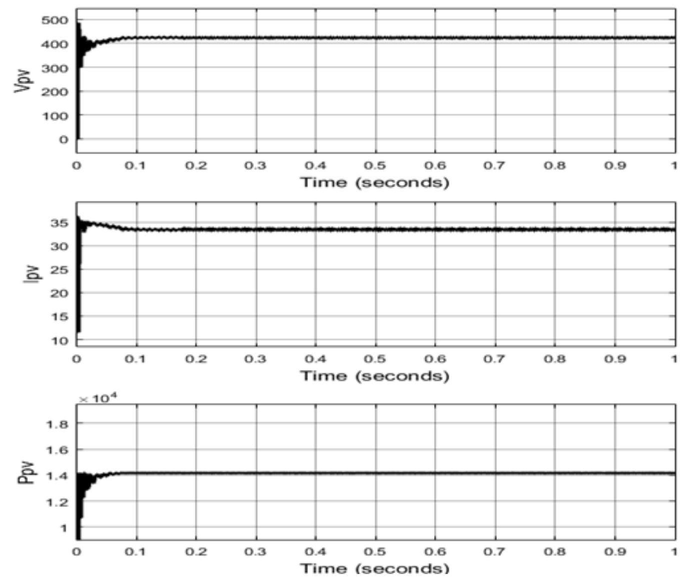

Figure 5: PV characteristics

The DC link voltage at the output of the PV array module before the three phase four legged inverter. The value of the DC link voltage is noted to be 830V which is generated as per the requirement of the grid voltage of 440Vrms line voltage.

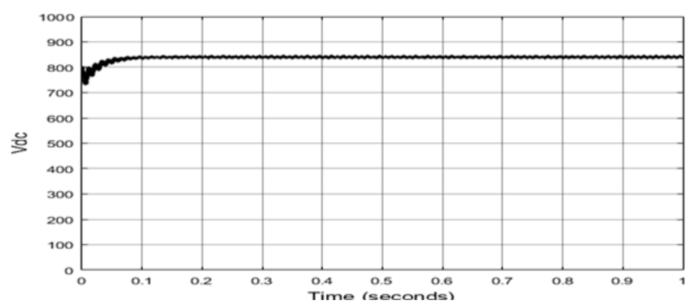

Figure 6: DC link voltage

The DC Link voltage is seen to be constant throughout the simulation of 1sec which reduced ripple content. The below figure 7 are the three phase voltages and currents of the PV inverter after the LC filter.

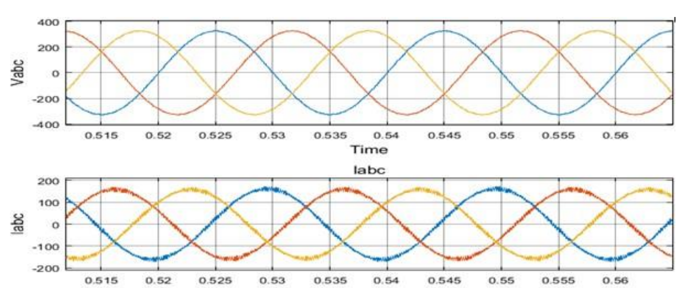

Figure 7: PV inverter three phase voltages and currents

International Journal of Engineering Applied Science and Management
ISSN (Online): 2582-6948
Vol. 7 Issue 7, July 2026

The figure 8 and 9 are the THDs of the PCC voltage and PV inverter current noted to be 0.75% and 3.63% respectively. These harmonics are very low and are maintained below 5% as per IEEE standard.

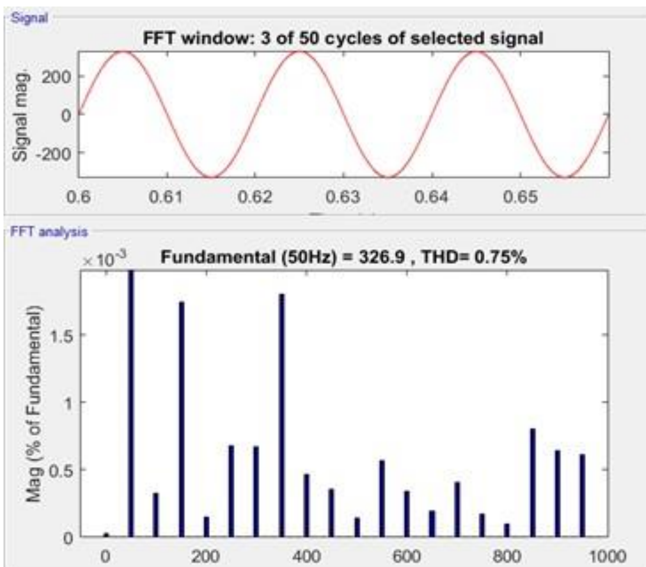

Figure 8: THD of PCC voltage

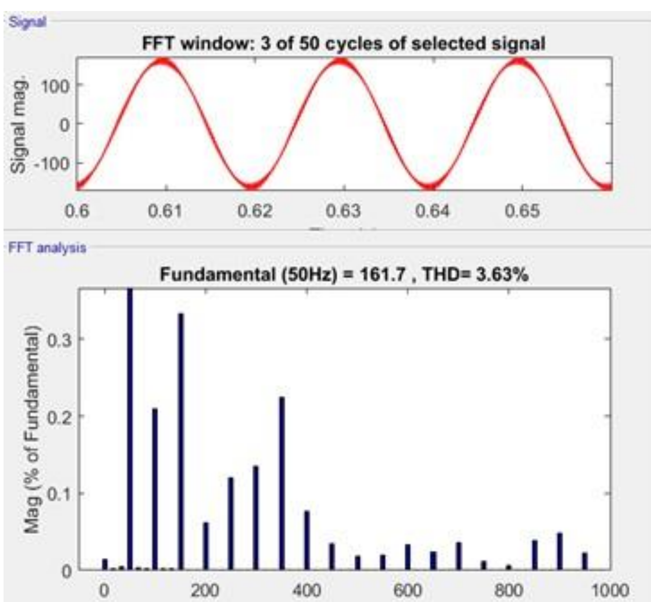

Figure 9: THD of PV inverter current

The below figure is the rules of the fuzzy controller integrated in the EV unit for current control of the EV battery. There are 49 rules set with seven membership functions in each input and output variable.

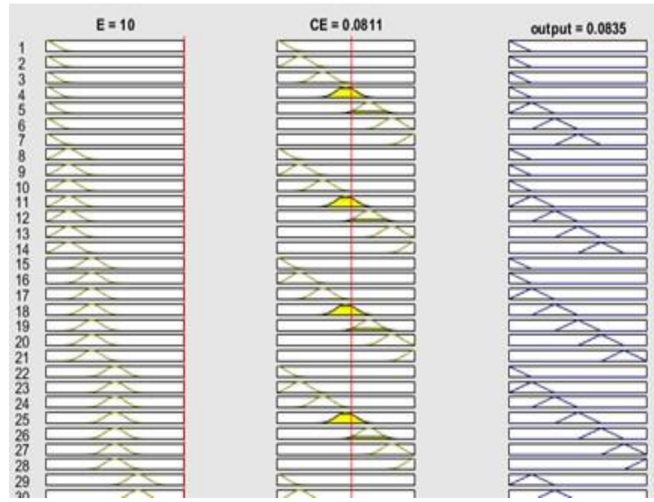

Figure 10: Fuzzy rules

The figure 11 is the EV battery comparison at the initial condition showing a drastic drop in initial peak overshoot with fuzzy logic controller.

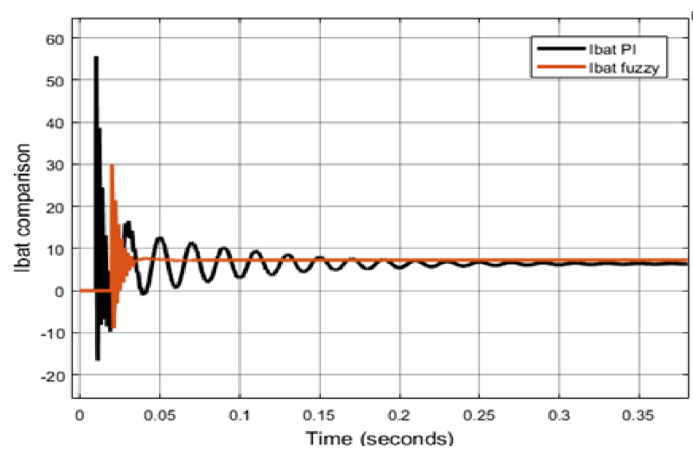

Figure 11: EV battery initial comparison Between PI and Fuzzy logic Controller

Table 1: Comparison table

Name of the parameter	PI	Fuzzy
Current Peak overshoot	55A	30A
Current ripple	15%	2.3%
Current settling time	0.4sec	0.04sec

IV. CONCLUSION

This paper presents an optimized design for developing power electronic converters that facilitate dual-way power transfer in a smart grid-based solar photovoltaic (SPV) building, enhancing both power loading/unloading capabilities and power quality. Additionally, the solar electric power generation system powers the batteries of electric vehicles (EVs) stored at the base of a modern building. The findings indicate that the SPV system effectively transmits power to the AC mains, while a three-phase voltage source converter (VSC) manages the DC-Link voltage. The batteries of the EVs and plug-in hybrid electric vehicles (PHEVs) are charged and discharged as needed. During peak solar intensity, a portion of the SPV current is utilized to charge the EVs and PHEV batteries. The simulation network is designed to evaluate the phase voltage and current components under non-linear load conditions. The total power injected from the PV array is recorded at 12 kW, with the average power contribution from the EVs being 3 kW. The total harmonic distortion (THD) values for the point of common coupling (PCC) voltage and inverter current are measured at 0.75% and 3.63%, respectively. These THD values are within the permissible limits set by IEEE 519 standards, which allow up to 5%. The results demonstrate that the integration of the smart grid and electric vehicle systems has improved power quality, power factor compensation, and voltage regulation. Furthermore, using a fuzzy logic controller has reduced the ripple, peak overshoot, and settling time in the EV battery current.

REFRENCES

[1] Allu Bhargav and Indrajit Sarkar, ―Solar Isolated Bi-directional Electric Vehicle Charger with Power Quality Enhancement Features‖, IAS Global Conference on Renewable Energy and Hydrogen Technologies (GlobConHT), IEEE 2023.

[2] Nikitha Paidimukkala and Narottam Das, ―Power Quality Improvement of a Solar Powered Bidirectional Smart Grid and Electric Vehicle Integration System‖, IEEE Sustainable Power and Energy Conference (iSPEC), IEEE 2022.

[3] M. Safayatullah, M.T. Elrais, S. Ghosh, R. Rezaii, I. Batarseh, A Comprehensive Review of Power Converter Topologies and Control Methods for Electric Vehicle Fast Charging Applications, IEEE Access 10 (2022) 40753–40793.

[4] C. Dhanamjayulu, S. R. Khasim, S. Padmanaban, G. Arunkumar, J. B. Holm-Nielsen, and F. Blaabjerg, ‗‗Design and implementation of multilevel inverters for fuel cell energy conversion system,'' IEEE Access, vol. 8, pp. 183690–183707, 2020.

[5] F.E.U. Reis, R.P. Torrico-Bascope, F.L. Tofoli, L.D.S. Bezerra, Bidirectional threelevel stacked neutral-point-clamped converter for electric vehicle charging stations, IEEE Access 8 (2020) 37565–37577.

[6] M. Abarzadeh, W.A. Khan, N. Weise, K. Al-Haddad, A.M. EL-Refaie, A new configuration of paralleled modular and multilevel converter controlled by an improved modulation method for 1MHZ, 1MW EV charger, IEEE Trans. Ind. Appl. 57 (2020) 3164–3178.

[7] M. N. Hamidi, D. Ishak, M. A. A. M. Zainuri, and C. A. Ooi, ‗‗Multilevel inverter with improved basic unit structure for symmetric and asymmetric source configuration,'' IET Power Electron., vol. 13, no. 7, pp. 1445–1455, May 2020

[8] C. Dhanamjayulu, G. Arunkumar, B. J. Pandian, and S. Padmanaban, ‗‗Design and implementation of a novel asymmetrical multilevel inverter optimal hardware components,'' Int. Trans. Electr. Energy Syst., vol. 30, no. 2, p. e12201, Feb. 2020.

[9] Y. Yang and H. Wen, ‗‗Adaptive perturb and observe maximum power point tracking with current predictive and decoupled power control for grid-connected photovoltaic inverters,'' J. Mod. Power Syst. Clean Energy, vol. 7, no. 2, pp. 422–432, Mar. 2019.

[10] A. K. Podder, N. K. Roy, and H. R. Pota, ‗‗MPPT methods for solar PV systems: A critical review based on tracking nature,'' IET Renew. Power Gener., vol. 13, no. 10, pp. 1615–1632, Jul. 2019.

[11] P. Bhatnagar, R. Agrawal, and K. K. Gupta, ‗‗Reduced device count version of single-stage switched-capacitor module for cascaded multilevel inverters,'' IET Power Electron., vol. 12, no. 5, pp. 1079–1086, May 2019.

[12] C. Dhanamjayulu and S. Meikandasivam, ‗‗Implementation and comparison of symmetric and asymmetric multilevel inverters for dynamic loads,'' IEEE Access, vol. 6, pp. 738–746, 2018.

[13] X. Liu, C. Zheng, J. Wu, J. Meng, D. I. Stroe, and J. Chen, ‗An improved state of charge and state of power estimation method based on genetic particle filter for lithium-ion batteries', *Energies*, vol. 13, no. 2, 2020.

[14] J. Tian, R. Xiong, W. Shen, and J. Wang, ‗A Comparative Study of Fractional Order Models on State of Charge Estimation for Lithium Ion Batteries', *Chinese J. Mech. Eng.*, 2020.

[15] J. Tian, R. Xiong, W. Shen, and J. Wang, ‗A Comparative Study of Fractional Order Models on State of Charge Estimation for Lithium Ion Batteries', *Chinese J. Mech. Eng.*, 2020.

[16] G.R.C. Mouli, J. Schijffelen, M. van den Heuvel, M. Kardolus, P. Bauer, A 10kW solar-powered bidirectional EV charger is compatible with Chademo and COMBO, IEEE Trans. Power Electron. 34 (2018) 1082–1098.

[17] Harsh Pratap Singh, Kedar Nath Singh, Lokendra Singh Songare, Nagendra Singh, Neeraj Arya, "Energy management systems using artificial intelligence: Future trends, challenges and solutions", Power System Management, CRC Press 2025, 227-238.

[18] Arvind Mewada, Maninder Singh, Harsh Pratap Singh, Nagendra Singh, "Voting ensemble-based machine learning models for early detection of power system faults", Power System Management, CRC Press 2025, 178-191

[19] A.R. Bhatti, Z. Salam, M.J.B.A. Aziz, K.P. Yee, A critical review of electric vehicle charging using solar photovoltaic, Int. J. Energy Res. 40 (2016) 439–461.

[20] A.R. Bhatti, Z. Salam, M.J.B.A. Aziz, K.P. Yee, R.H. Ashique, Electric vehicles charging using photovoltaic: status and technological review, Renew. Sustain. Energy Rev. 54 (2016) 34–47.