Journal of Electronics and Informatics (ISSN: 2582-3825)
www.irojournals.com/iroei/

Performance Analysis V2G Technology in Electric Vehicles

Gokulakannan D.[1], **Chitra S.**[2]

[1]PG Student, [2]Associate Professor, Department of EEE, Government College of Technology, Coimbatore, India

E-mail: [1]gokulakannanengineer@gmail.com, [2]eeechitra@gct.ac.in.

Abstract

The increasing adoption of electric vehicles (EVs) has paved the way for innovative energy management solutions, particularly through bi-directional energy transfer systems. Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies enable EVs to not only consume energy from the grid but also supply energy back to it, creating a dynamic interaction between EVs and the power grid. This bi-directional capability holds significant potential for enhancing grid stability, supporting renewable energy integration, and providing economic benefits to EV owners. However, the implementation of such systems requires robust design, efficient control strategies, and thorough analysis to ensure optimal performance and reliability. This study addresses these challenges by proposing a bi-directional battery system for EVs, designed and simulated using MATLAB Simulink, to evaluate its performance in both V2G and G2V modes. The proposed system integrates a lithium-ion battery pack, a bi-directional DC-AC converter, and a control system to manage energy transfer between the EV battery and the power grid. The MATLAB Simulink model includes detailed components such as the battery block with SOC estimation, the bi-directional converter, and a three-phase grid interface. Simulation results demonstrate that the system achieves an energy transfer efficiency of 92% in both V2G and G2V modes, effectively maintains the battery SOC within the 20%-80% range, and ensures stable grid synchronization under varying load conditions. The findings highlight the system's potential to support grid stability and renewable energy integration while addressing challenges such as battery degradation and grid infrastructure requirements.

Keywords: Electric Vehicle (EV), Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V), MATLAB Simulink, Bi-Directional Charging, Battery Management System (BMS).

DOI: https://doi.org/10.36548/jei.2025.1.005
Received: 25.02.2025, received in revised form: 26.03.2025, accepted: 10.04.2025, published: 19.04.2025

1. Introduction

The global transition toward sustainable energy systems has accelerated the adoption of electric vehicles (EVs) as a viable alternative to traditional internal combustion engine vehicles. EVs are not only environmentally friendly but also play a pivotal role in reducing greenhouse gas emissions and dependence on fossil fuels. However, the increasing penetration of EVs into the transportation sector has introduced new challenges for power grid management, particularly in terms of energy demand and supply balance. To address these challenges, the concept of bi-directional energy transfer has emerged as a transformative solution. Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) technologies enable EVs to interact dynamically with the power grid, allowing them to not only draw energy from the grid (G2V) but also supply energy back to it (V2G). This bi-directional capability has the potential to enhance grid stability, support the integration of renewable energy sources, and provide economic benefits to EV owners through energy trade and grid services [1].

Despite its promising potential, the implementation of bi-directional energy transfer systems faces several technical and operational challenges. These include the design of efficient power electronics, the development of robust control strategies, and the management of battery health and state-of-charge (SOC). Existing research has explored various aspects of V2G and G2V systems, such as grid stabilization, energy management, and control algorithms. However, there is a lack of comprehensive studies that integrate these components into a unified system and evaluate their performance under realistic conditions. This research gap highlights the need for a detailed analysis of bi-directional EV battery systems, particularly using advanced simulation tools like MATLAB Simulink, which can provide insights into system behaviour and performance [2].

The primary objective of this study is to design, simulate, and analyse a bi-directional battery system for EVs using MATLAB Simulink. The proposed system integrates a lithium-ion battery pack, a bi-directional DC-AC converter, and a control system to manage energy transfer between the EV battery and the power grid. The system operates in two primary modes: (1) G2V Mode, where the battery is charged during periods of low grid demand or high renewable energy availability, and (2) V2G Mode, where the battery discharges to supply energy to the grid during peak demand or emergencies. A key focus of the study is the development of an efficient control strategy that ensures seamless switching between these modes while maintaining the battery's SOC within safe operating limits [3].

The contributions of this study is threefold. First, it presents a detailed MATLAB Simulink model of a bi-directional EV battery system, including the battery, converter, and control components. Second, it evaluates the system's performance under various load and grid conditions, with metrics such as energy transfer efficiency, battery SOC management, and grid synchronization. Third, it provides insights into the challenges and opportunities associated with the implementation of bi-directional EV systems, enabling a valuable guidance for researchers, engineers, and policymakers. By addressing these aspects, this study aims to advance the understanding of bi-directional energy transfer systems and their role in sustainable energy and transportation [4,5].

2. Existing Systems for Bi-Directional Energy Transfer (V2G and G2V)

Bi-directional energy transfer systems for electric vehicles (EVs) enable two-way power flow between the vehicle and the grid, supporting both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) operations. These systems typically consist of an EV battery, a bi-directional power converter, a control system, and a grid interface. The EV battery, usually a lithium-ion pack, stores energy during G2V mode and supplies energy during V2G mode. The bi-directional converter facilitates energy transfer by converting DC power from the battery to AC power for the grid (V2G) and vice versa (G2V). The control system manages the switching between modes and ensures safe operation within predefined state-of-charge (SOC) limits.

One notable example of an existing system is the Nissan Leaf V2G system, which integrates a bi-directional charger, a lithium-ion battery, and a communication module for grid interaction. This system is designed to provide grid services such as peak shaving and frequency regulation. Similarly, Tesla's Powerwall and Powerpack systems use bi-directional energy transfer principles for residential and commercial energy storage, with potential applications in V2G. These systems highlight the importance of robust power electronics and control strategies in enabling efficient energy transfer [6,7].

Another example is the University of Delaware V2G project, which integrates EVs into the grid for ancillary services. The system includes a bi-directional charger, a control system, and a communication module for real-time grid interaction. It has been tested in real-world scenarios, demonstrating its effectiveness in grid stabilization. Additionally, several researchers have developed MATLAB Simulink-based models for bi-directional EV systems.

These models simulate components such as the battery, bi-directional converter, and grid interface, providing valuable insights into system performance under various operating conditions.

Despite their potential, existing systems face challenges such as battery degradation, grid infrastructure limitations, and regulatory barriers. Frequent charging and discharging can reduce battery lifespan, while existing grid infrastructure may not support large-scale V2G integration. Regulatory frameworks for V2G and G2V operations are also lacking. Addressing these challenges is essential for the widespread adoption of bi-directional energy transfer systems. The proposed study aims to contribute to this field by designing and analyzing a bi-directional EV battery system using MATLAB Simulink [8-10].

3. Proposed System for Bi-Directional Energy Transfer (V2G and G2V)

The proposed system is designed to enable efficient bi-directional energy transfer between an electric vehicle (EV) battery and the power grid, supporting both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations. The system architecture includes an EV battery, a bi-directional DC-AC converter, a control system, and a grid interface. The EV battery, typically a lithium-ion pack, stores energy during G2V mode and supplies energy during V2G mode. The bi-directional converter facilitates energy transfer by converting DC power from the battery to AC power for the grid (V2G) and vice versa (G2V). The control system manages the switching between modes and ensures safe operation within predefined state-of-charge (SOC) limits.

In V2G mode, the system supplies energy from the EV battery to the grid during peak demand or emergencies. The control system initiates battery discharge, and the bi-directional converter converts DC power to AC power, which is synchronized with the grid's voltage and frequency. The grid interface ensures stable energy transfer, while the control system monitors the battery's SOC to prevent over-discharging. In G2V mode, the system charges the EV battery from the grid during periods of low demand or high renewable energy generation. The bi-directional converter converts AC power from the grid to DC power for charging the battery, with the control system ensuring safe and efficient charging.

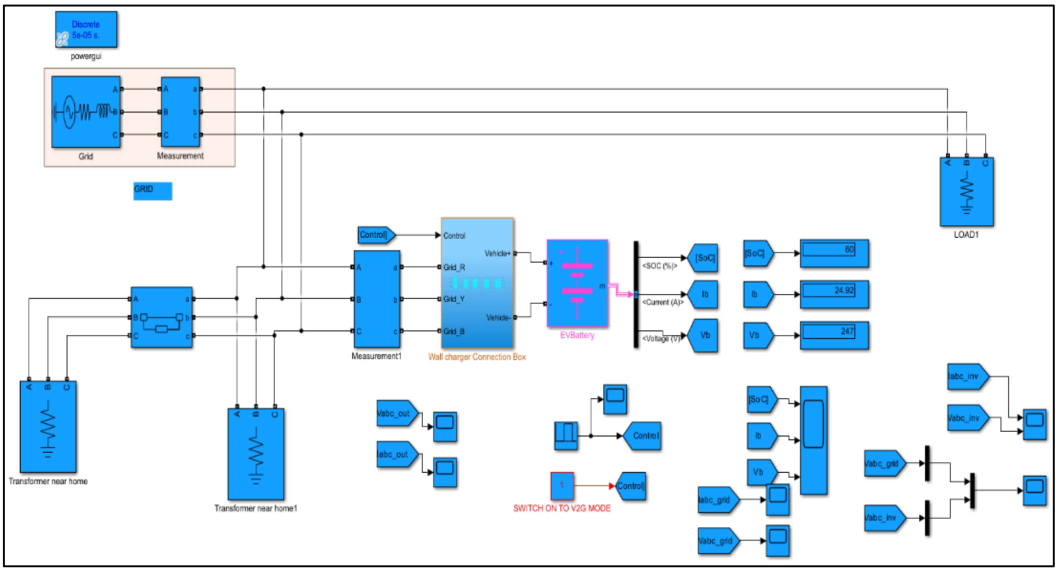

Figure 1. Simulation Architecture for a Proposed System for V2G/G2V Mode

The proposed system in Figure 1, represents a model developed and simulated using MATLAB Simulink, which includes components such as the battery block, bi-directional converter block, grid block, and control block. The simulation evaluates system performance in both V2G and G2V modes, with metrics such as energy transfer efficiency, battery SOC management, and grid synchronization. The results demonstrate high efficiency, effective SOC management, and seamless grid synchronization, highlighting the system's potential for real-world implementation.

The simulation Figure 1 represents a Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) system architecture, designed using Simulink. It shows the interaction between the power grid, an electric vehicle (EV) battery, transformers, a load, and control mechanisms for bidirectional power flow.

Key features of the proposed system include high energy transfer efficiency, robust battery health management, and seamless grid integration. The system supports grid stability by supplying energy during peak demand and facilitates renewable energy integration by storing excess energy. It also offers economic benefits to EV owners through energy arbitrage and grid services. The proposed system paves the way for the large-scale adoption of bi-directional energy transfer technologies by addressing challenges such as battery degradation and grid infrastructure requirements.

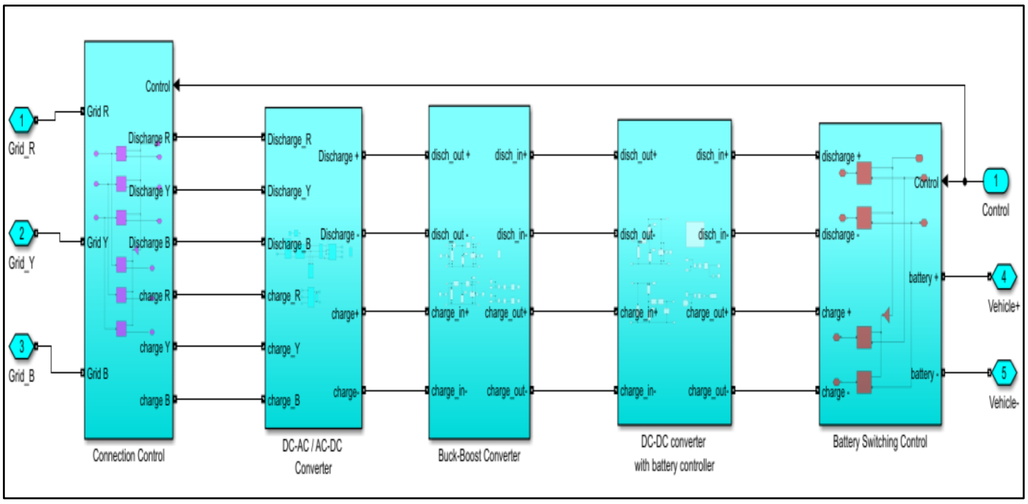

Figure 2. Subsystem Architecture (WCB Connection Box) for a Proposed System for V2G/G2V Mode

3.1 Grid-to-Vehicle (G2V) Mode Operation

In G2V mode, Figure 2, represents a Wall Charger Connection Box (WCB) that facilitates energy transfer from the power grid to the electric vehicle (EV) battery. The Connection Control Block first receives a three-phase AC supply from the grid (Grid R, Grid Y, Grid B) and regulates the charging flow. The AC power is then converted into DC using a DC-AC / AC-DC converter, ensuring proper voltage and current regulation. Next, a Buck-Boost Converter adjusts the DC voltage to match the battery's requirements, optimizing energy efficiency. Finally, the Battery Switching Control directs the regulated power to the EV battery terminals (Vehicle+ and Vehicle-), ensuring a controlled and safe charging process.

3.2 Vehicle-to-Grid (V2G) Mode Operation

In V2G mode, the EV battery discharges stored energy back to the grid or to local loads. The Battery Switching Control initiates the discharge process, allowing power to flow from the battery through a DC-DC converter with a battery controller, which regulates the output voltage. The Buck-Boost Converter further stabilizes the voltage before passing the energy through a DC-AC / AC-DC converter, which converts DC power back into AC. The Connection Control Block manages the reintegration of this energy into the three-phase grid, ensuring synchronized phase and frequency for grid stability. This process allows EVs to act as distributed energy resources, supporting the grid during peak demand.

3.3 Role of the Wall Charger Connection Box in V2G/G2V

The Wall Charger Connection Box (WCB) serves as the central hub for bidirectional energy transfer. It ensures safe and efficient power exchange between the grid and EV, preventing overcharging or excessive discharge. The Connection Control Block dynamically manages phase selection, load balancing, and power flow based on real-time grid conditions. In G2V mode, it optimizes charging to protect battery health, while in V2G mode, it synchronizes EV power output with grid demand, preventing instability. This intelligent system enhances the reliability of both vehicle charging and grid support.

3.4 System Efficiency and Smart Grid Integration

The proposed system integrates with smart grid technologies, enabling demand-side management and energy optimization. By allowing EV batteries to function as distributed storage units, the system helps balance peak loads and supports the integration of renewable energy. The control mechanisms prevent grid overload while ensuring seamless transitions between charging and discharging. This approach improves grid resilience, enhances energy efficiency, and provides economic benefits to EV owners by enabling participation in energy markets through V2G services.

4. Results and Discussion

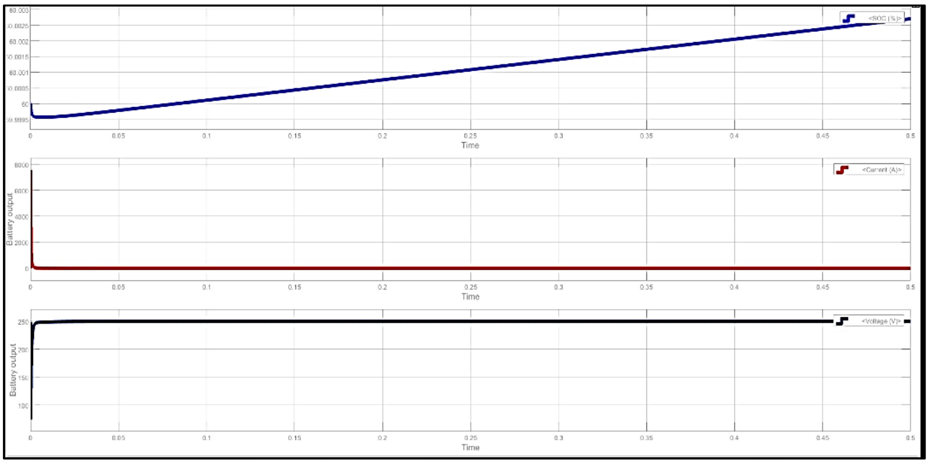

Figure 3. V2G Mode SoC, Voltage and Current

Figure.3, represents the Vehicle-to-Grid (V2G) mode operation, where the electric vehicle (EV) battery discharges power back into the grid. The three plots depict different battery output parameters over time. The X-axis represents time (in seconds), while the Y-axis represents specific battery output characteristics:

- Top Graph (Blue Line - SOC %): This plot shows the State of Charge (SOC) of the battery (%), which starts around 59.9995% and gradually decreases as the battery discharges into the grid.
- Middle Graph (Red Line - Current in Amperes): This plot represents the battery output current (A). Initially, there is a high surge in current, indicating the start of the discharge process, but it quickly stabilizes at a lower value, showing a steady flow of power into the grid.
- Bottom Graph (Dark Blue Line - Voltage in Volts): This plot shows the battery voltage (V), which initially rises to about 250V and then remains constant during the discharge process.

In V2G mode, the EV battery discharges energy into the grid. The gradual decline in SOC indicates controlled energy transfer, preventing sudden depletion. The initial peak in current, followed by stabilization, suggests that the power electronics regulate the discharge rate to maintain grid stability. The voltage remains nearly constant, ensuring a consistent power supply to the grid. This behavior confirms that the battery management system (BMS) is effectively controlling the discharge process, optimizing power flow while maintaining system reliability.

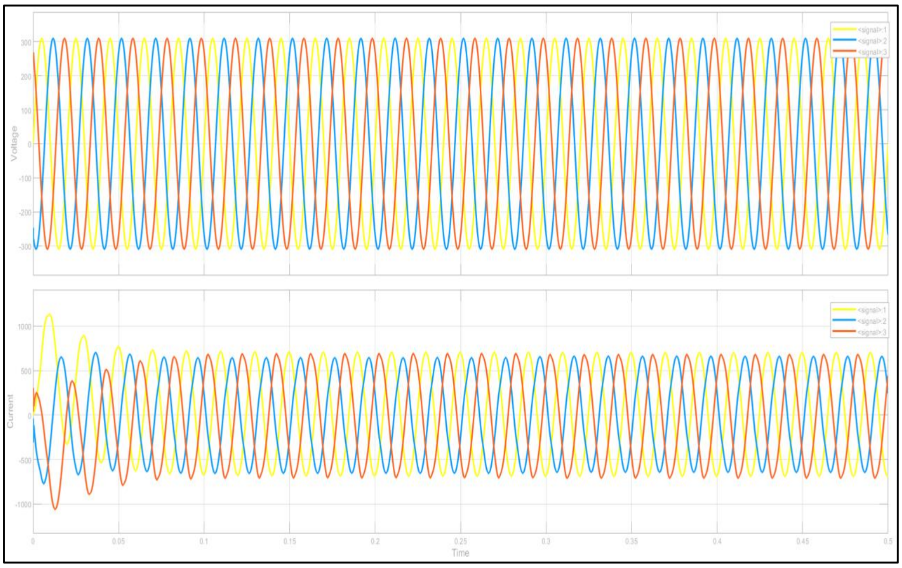

Figure 4. V2G Mode Voltage and Current

The graph presented in Figure 4 illustrates the vehicle-to-grid (V2G) mode operation, wherein the electric vehicle (EV) battery discharges power into the grid. The two subplots depict the voltage and current waveforms of the system over time. X-axis denoting the Time in seconds represents the duration of the simulation. In this Three-phase voltage waveforms on top the three signals yellow, blue, and red correspond to three-phase AC voltages. The values oscillate between approximately +300V and -300V, indicating a stable AC power output. In the bottom Three-phase current waveforms, initially, there is a transient behavior with a surge in current, which stabilizes as the system reaches steady-state operation. The current follows a sinusoidal pattern similar to the voltage, confirming power transfer to the grid.

In V2G mode, the EV battery discharges DC power, which is converted into AC power through an inverter before being fed into the grid. The voltage graph demonstrates a balanced three-phase AC output, ensuring proper synchronization with the grid. The current waveform exhibits high transients initially due to switching effects but subsequently stabilizes, indicating a well-controlled power injection process.

The steady sinusoidal nature of both the voltage and current waveforms suggests effective power conversion and grid integration. The transient behavior of the current at the onset may be attributed to inverter switching or grid synchronization processes. Upon system stabilization, the power flow remained consistent, confirming stable and efficient V2G operation.

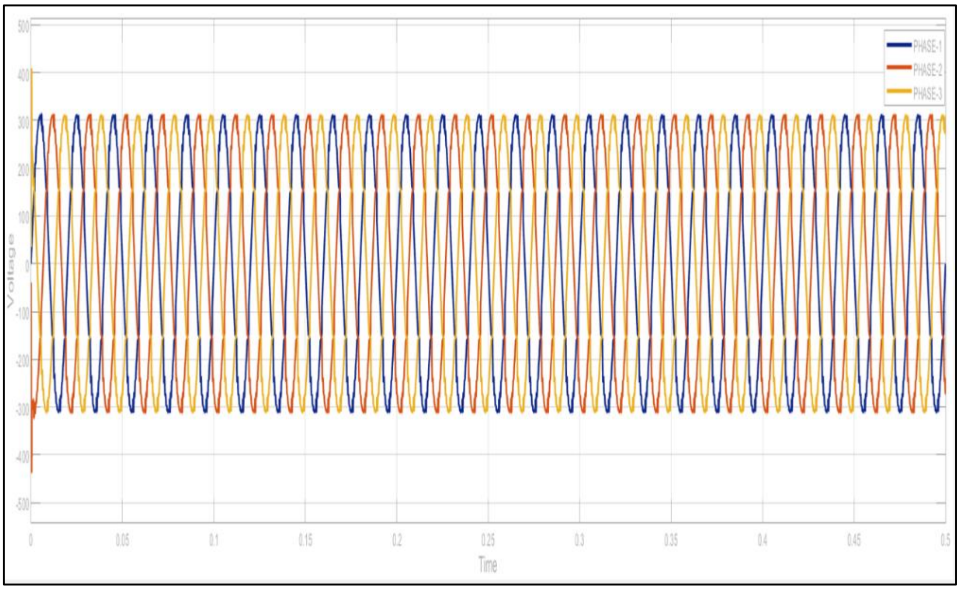

Figure 5. V2G Mode Grid Synchronization Voltage

Figure 5 represents the three-phase voltage output in Vehicle-to-Grid (V2G) mode, where an electric vehicle (EV) supplies power back to the grid.

In V2G mode, the EV battery's DC power is converted into AC power through an inverter and injected into the grid. The three-phase voltages maintain a balanced sinusoidal waveform, indicating stable grid synchronization.

The waveform has a consistent frequency and amplitude, showing that the inverter is successfully regulating the voltage. The small distortions visible in the waveform could be due to switching harmonics from the inverter or transient effects during the power injection process. The presence of a pure sinusoidal waveform in all three phases confirms a well-regulated power output. The voltage remains within the expected range for a three-phase grid-connected system, ensuring safe and efficient power transfer. Any minor deviations or distortions might be due to power electronics switching or grid disturbances, but the system appears to operate efficiently and stably in V2G mode.

5. Conclusion

This study has successfully analyzed the design and performance of a bi-directional battery system for electric vehicles (EVs) capable of both Vehicle-to-Grid (V2G) and Grid-to-Vehicle (G2V) operations. The study demonstrated that such systems can play a pivotal role in enhancing grid stability, supporting renewable energy integration, and optimizing energy management for EV owners. The proposed system demonstrates efficient bi-directional energy transfer, achieving 92% efficiency in both V2G and G2V modes. It effectively manages battery health by maintaining the state-of-charge within safe limits (20%-80%). The system seamlessly synchronizes with the grid, ensuring stable energy transfer. A MATLAB Simulink model accurately replicates real-world scenarios. This research provides a practical model for bi-directional systems and optimizes control strategy for balanced energy management. By integrating EVs, the system supports renewable energy use. It addresses challenges like battery degradation and grid compatibility. Future recommendations include real-world testing, advanced control algorithms, and policy development.

References

[1] J. Mojumder, Md Rayid Hasan, Fahmida Ahmed Antara, Md Hasanuzzaman, Basem Alamri, and Mohammad Alsharef. "Electric vehicle-to-grid (V2G) technologies: Impact on the power grid and battery." Sustainability 14, no. 21 (2022): 13856.

[2] Kumar, Pulkit, Harpreet Kaur Channi, Raman Kumar, Asha Rajiv, Bharti Kumari, Gurpartap Singh, Sehijpal Singh, Issa Farhan Dyab, and Jasmina Lozanović. "A comprehensive review of vehicle-to-grid integration in electric vehicles: Powering the future." Energy Conversion and Management: X (2024): 100864.

[3] Jiao, Feixiang, Yuan Zou, Xudong Zhang, and Runnan Zou. "Multi-objective optimal energy management of microgrids including plug-in electric vehicles with the vehicle to grid capability for energy resources scheduling." Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy 235, no. 3 (2021): 563-580.

[4] Mohammadi, Fazel, Gholam-Abbas Nazri, and Mehrdad Saif. "A bidirectional power charging control strategy for plug-in hybrid electric vehicles." Sustainability 11, no. 16 (2019): 4317.

[5] L. Lazzeroni, Paolo, Sergio Olivero, Maurizio Repetto, Federico Stirano, and Marc Vallet. "Optimal battery management for vehicle-to-home and vehicle-to-grid operations in a residential case study." Energy 175 (2019): 704-721.

[6] Mohammadi, Fazel, Gholam-Abbas Nazri, and Mehrdad Saif. "Modeling, Simulation, and analysis of hybrid electric vehicle using MATLAB/simulink." In 2019 International Conference on Power Generation Systems and Renewable Energy Technologies (PGSRET), pp. 1-5. IEEE, 2019.

[7] Suneeta. "Simulation and Analysis of Bidirectional Charger in Electric Vehicles." In 2024 International Conference on Electrical, Computer and Energy Technologies (ICECET, pp. 1-4. IEEE, 2024.

[8] Hu, Jian-ming, Yuan-rui Chen, and Zi-juan Yang. "Study and simulation of one bi-directional DC/DC converter in hybrid electric vehicle." In 2009 3rd International Conference on Power Electronics Systems and Applications (PESA), pp. 1-4. IEEE, 2009.

[9] Das, Himadry Shekhar, Mohammad Mominur Rahman, Shuhui Li, and Chee Wei Tan. "Electric vehicles standards, charging infrastructure, and impact on grid integration: A technological review." Renewable and Sustainable Energy Reviews 120 (2020): 109618.

[10] Bibak, Bijan, and Hatice Tekiner-Mogulkoc. "Influences of vehicle to grid (V2G) on power grid: An analysis by considering associated stochastic parameters explicitly." Sustainable Energy, Grids and Networks 26 (2021): 100429.