Dynamic On-Demand Energy Sharing for EVs

Dr. S.M. Kannan [1], Dr.S.Venkatesan[2]
S. Joshua[3], K.B. Lakshmi Narayanan[4], R. Kaushal[5], R.R. Dhaya Vishnu[6]

[1] Prof & HOD/EEE, Department of Electrical & Electronics Engineering, K.L.N. College of Engineering, Tamil Nadu, India
[2] Prof/EEE, Department of Electrical & Electronics Engineering, K.L.N. College of Engineering, Tamil Nadu , India
[3, 4, 5,6] UG Scholar, Department of Electrical & Electronics Engineering, K.L.N. College of Engineering, Tamil Nadu, India

***

Abstract - Electric vehicle-to-vehicle (V2V) charging enables EVs to share energy, but current solutions face cost and efficiency issues. This work proposes a direct battery-to-battery V2V charging method using type-2 AC charger input ports and switches, bypassing active rectifiers to reduce conversion losses. A Battery Management System (BMS) monitors battery temperature and voltage to prevent overcharging and overheating, ensuring safe and efficient charging. The method's effectiveness is validated through MATLAB/Simulink simulations and a scaled prototype.

Keywords- Vehicle-to-Vehicle (V2V), Charging-Electric Vehicle (EV), Direct Battery Connection, Power Transfer Efficiency, Type-2 AC Charger.

1.INTRODUCTION

Electric vehicles (EVs), which rely on electric motors instead of gasoline engines, have gained substantial traction, particularly among environmentally conscious consumers. Interestingly, the origins of EV technology trace back to the early 19th century. Although the exact origin of the first EV remains unclear, electric motors were already in use in the early 1800s. In 1828, Ányos Jedlik created a small-scale model car powered by an electric motor. Later, between 1832 and 1839, Scottish inventor Robert Anderson developed a larger electric motor that powered a carriage. To assess the practicality of this method, a detailed MATLAB/Simulink simulation is carried out to analyze various V2V charging scenarios. Additionally, a scaled-down experimental prototype is constructed to confirm its real-world feasibility. The findings show that the direct battery connection method delivers a highly effective and practical solution for V2V power transfer, paving the way for more advanced and efficient EV charging systems.

Although early electric vehicles failed to achieve widespread success, they laid the foundation for further technological advancements. In 1835, two small-scale electric vehicles were independently built—one in Holland and another in the United States by Thomas Davenport. Davenport later constructed the first battery-powered electric car, but its range was limited by the use of non-rechargeable batteries. Over time, inventors like French engineer Gaston Planté worked to enhance battery technology, but practical EV adoption remained challenging.

In modern EV technology, vehicle-to-vehicle (V2V) charging systems primarily rely on either off-board power-sharing units or on-board type-2 chargers. While off-board systems provide flexibility, they increase cost and require additional space. On-board type-2 charger-based V2V power transfer, however, involves multiple conversion stages, leading to energy loss from redundant power processing. These limitations highlight the need for a more streamlined and efficient V2V charging solution.

This work presents a novel V2V charging approach that enables direct battery-to-battery energy exchange between two EVs using type-2 AC charger input ports and switches. Unlike traditional methods that rely on active rectifiers for power conversion, this method bypasses unnecessary rectification and conversion stages. By using a minimal set of switches, the system creates a direct energy transfer path, reducing power losses and enhancing overall efficiency.

2. PROPOSED METHOD

On-board Type-1 and Type-2 electric vehicle (EV) chargers typically include an AC-to-DC converter (active rectifier) stage, followed by a DC-DC converter that manages constant current and constant voltage (CCCV) charge control. A vehicle-to-vehicle (V2V) charging method can be implemented by connecting the input ports of two Type-1 chargers, as depicted in Figure 1(a). In this method, the provider EV's battery delivers DC power, which is initially converted into single-phase AC using its bidirectional Type-1 charger. This AC output is then supplied to the receiver EV's Type-1 charger, which converts it back to DC for battery charging. However, this method introduces energy losses due to multiple conversion stages, thereby lowering the overall charging efficiency.

An alternative V2V charging technique involves directly connecting the DC-links of the two EVs using mechanical switches, as shown in Figure 1(b). However, direct access to the DC-link of the battery-side DC-DC converter is generally not available in practical scenarios, making this method difficult to implement.

To address these limitations, this work proposes a V2V charging strategy that utilizes on-board Type-2 chargers. By directly linking the Type-2 charging ports of two EVs, this approach removes the need for additional hardware or extra power inlet ports. The proposed method uses the active rectifier stages of the chargers as a connection interface between the two EV batteries, which reduces the number of conversion stages in the power transfer process. Fewer conversion stages result in fewer active switching components, thereby reducing both switching and conduction losses, and significantly improving overall efficiency.

The proposed system features a mode selection logic that determines whether the converter should operate in buck or boost mode based on the voltage levels of the batteries. It also regulates the direction of power flow according to the user's preference, enabling energy transfer between EVs even when their battery voltage ratings differ. Additionally, the system includes a **Battery Management System (BMS)** that continuously monitors the battery's temperature and voltage levels during the V2V charging process. The BMS ensures safe and efficient charging by preventing overheating, overcharging, and deep discharge. The monitored data, including real-time temperature and voltage levels, is displayed to the user, allowing better control and monitoring of the charging process.

In this configuration, the two EVs are connected through their existing Type-2 charging ports. Power transfer is facilitated using the three-phase active rectifier switches. Specifically, during V2V charging, the top switch of one phase (phase-a, referred to as S1) and the bottom switch of another phase (phase-c, referred to as S6) of the provider EV's active rectifier-1 are turned ON. At the same time, the corresponding switches (S'1 and S'6) of the receiver EV's active rectifier-2 are also switched ON. This direct link between the intermediate DC-links of both EVs is illustrated in Figure 2.

Throughout the V2V charging process, the four switches (S1, S6, S'1, and S'6) remain engaged, forming a dual bidirectional buck-boost converter. This arrangement enables controlled energy transfer between the two EVs, regardless of variations in their battery voltage levels. Since the active rectifiers of both Type-2 chargers serve as an interface for linking the two DC-links, their usual rectification function is bypassed, and all other switches of the rectifiers remain OFF during V2V charging. Depending on the battery voltage levels of the two EVs, the system automatically operates in different energy transfer modes, ensuring effective and flexible power exchange.

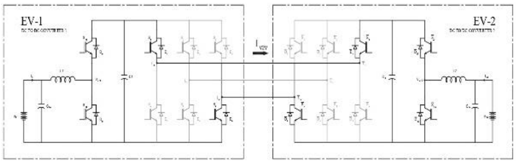

Fig. 2. Proposed topology for V2V operation.

2.1. V2V Case-1: Vbat1 < Vbat2

When the battery voltage of EV-1 is lower than that of EV-2, and their roles as provider and receiver are defined, two possible operating modes are identified. In the first case, when EV-1 acts as the provider, power flows forward, requiring a boost operation to increase the voltage before transferring energy to EV-2. On the other hand, in the second case, when the power flow is reversed and EV-2 becomes the provider, a buck operation is necessary to step down the voltage before supplying power to EV-1. These operational modes ensure effective energy transfer between the two EVs, regardless of their battery voltage differences.

1) Forward Step-Up Mode (EV1 as Provider and EV2 as Receiver):

In this mode, EV-1 functions as the charge provider, and EV-2 acts as the charge receiver, with battery-1 having a lower voltage than battery-2. When the two EV batteries are directly connected using the proposed method by activating switches S1, S6, S'1, and S'6, the voltage of EV-1's battery is stepped up to match that of EV-2 by operating DC-DC converter-1 in boost mode. During the ON period of switch Sb1, inductor L1 stores energy from EV-1's battery, while switch Sa1 operates in complementary mode to Sb1.

When Sb1 turns OFF, Sa1 turns ON, allowing energy transfer from EV-1's battery and inductor L1 to EV-2's battery through S1, S'1, Sa2, and inductor L2. To enable power reception from the DC-links, switch Sa2 stays ON throughout the V2V charging process, ensuring that Vdc1 matches Vdc2, which equals Vbat2. Meanwhile, switch Sb2 switches in complement to Sa2, as illustrated in the figure.

2) Reverse Step-Down Mode (EV1 as Receiver and EV2 as Provider):

Similar to the forward step-up mode, in this reverse step-down mode, the EV batteries are linked by switching ON S1, S6, S'1, and S'6 of active rectifiers 1 and 2. DC-DC converter-1 operates in buck mode to transfer power from EV-2's battery to EV-1's battery. Since Vbat1 is lower than Vbat2, diode Da2 becomes forward biased, ensuring that Vbat2 equals Vdc1, which equals Vdc, allowing EV-2's battery to provide power to EV-1 through the DC-link.

During the ON period of switch Sa1, energy from EV-2's battery is supplied to EV-1's battery via inductor L1, Da2, S'1, and inductor L2, as shown in Figure 4(a). When Sa1 switches OFF, the stored energy in inductor L1 is released through switch Sb1, which switches in complement to Sa1, as depicted in Figure 4(b).

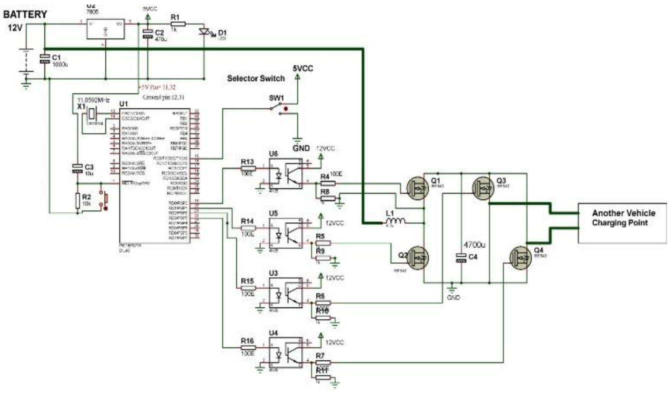

Fig. 3. Forward boost V2V mode

2.2. V2V Case-2: Vbat1 = Vbat2

In this scenario, where both EV battery voltages are equal, the DC-DC converters must be controlled such that one operates in a current-controlled boost mode while the other functions in a current-controlled buck mode.

1) Forward Step-Up Mode (EV1 as Provider and EV2 as Receiver):
In this mode, where Vbat1 equals Vbat2, energy transfer from EV-1 to EV-2 is carried out by operating DC-DC converter-1 in boost mode and DC-DC converter-2 in buck mode, both under closed-loop current control. During the ON period of switch Sb1, inductor L1 stores energy from EV-1's battery, while switch Sa1 switches in complement to Sb1. Simultaneously, switch Sb2 of DC-DC converter-2 is turned ON to allow inductor L2 to freewheel energy, with switch Sa2 complementarily switched to Sb2, as shown in Figure 5(a).

When Sb1 and Sb2 switch OFF, switches Sa1 and Sa2 turn ON, facilitating energy flow from EV-1's battery to EV-2's battery through L1, S1, S'1, and L2, as shown in Figure 5(b). This mode can also be achieved by controlling the provider EV's DC-DC converter in voltage control mode to regulate the DC-link voltage at a level higher than the EV battery voltage, while the receiver-side DC-DC converter operates in current control mode.

2) Reverse Step-Up Mode (EV1 as Receiver and EV2 as Provider):
This mode is similar to the forward step-up mode, where Vbat1 equals Vbat2, but with the direction of power flow reversed. In this case, DC-DC converter-2 functions in boost mode, while DC-DC converter-1 operates in buck mode under closed-loop current control. Alternatively, voltage control mode can also be applied to regulate the power transfer process in this mode.

2.3 V2V Case-3: Vbat1 > Vbat2

The converter operation in this scenario is similar to Case-1, but with the direction of power flow reversed.

1) Reverse Step-Up Mode (EV1 as Receiver and EV2 as Provider):
This mode resembles the forward boost mode, where Vbat1 is less than Vbat2, but with the power flow reversed. In this case, DC-DC converter-2 of EV-2 functions in boost mode, while switch Sa1 of the DC-DC converter-1 in EV-1 stays continuously ON.

2) Forward Step-Down Mode (EV1 as Provider and EV2 as Receiver):
This mode mirrors the reverse buck mode, where Vbat1 is less than Vbat2, but with reversed power flow. In this case, DC-DC converter-2 of EV-2 functions in buck mode, while switch Sa1 of the DC-DC converter-1 in EV-1 stays continuously ON.

3. REGULATION STRATEGY FOR THE PROPOSED V2V METHOD

The charging rate and the quantity of energy transferred in the proposed V2V method are regulated by controlling the on-board converters. The mode selector flow, as illustrated in Figure 6, identifies the suitable V2V mode based on the battery voltages of EV-1 and EV-2, as well as their respective roles as provider and receiver. Depending on the selected operating mode, the on-board charger converters are adjusted accordingly to enable V2V energy transfer.

3.1 Operation of the Active Rectifiers as a V2V Interface

During standard three-phase AC charging using a Type-2 charger, the active rectifier functions in d-q control mode, converting three-phase AC to DC while ensuring unity power factor at the grid terminals. However, in the proposed V2V charging method, the active rectifier is reconfigured to serve as an interface for linking and enabling energy exchange between the two EV batteries. Once the Type-2 charger ports are connected for V2V charging, the gating pulses for switches S1 and S6 of the active rectifier-1 in EV-1, along with switches S1 and S'6 of the active rectifier-2 in EV-2, remain continuously activated throughout the V2V charging process across all operating modes.

3.2 Regulation of DC–DC Converters

In the proposed V2V charging strategy using onboard chargers, the DC-DC converters of Type-2 chargers operate under a closed-loop current control system. For forward step-up and reverse step-down modes, where Vbat1 is lower than Vbat2, the inductor current IL1 of DC-

DC converter-1 is regulated using a closed-loop mechanism. The error between the reference current IL* and the actual inductor current IL1 is processed through a PI controller, which determines the duty cycle for switch Sa1, while switch Sb1 operates in complementary mode to Sa1, as shown in Figure 7. The gating signal for switch Sa2 remains continuously active during this mode.

The transfer function used to configure the PI controller for DC-DC converter-1 is defined by the duty cycle (D) and the load resistance (R2), which corresponds to the charging current of EV-2's battery. The proposed V2V method enhances efficiency, minimizes energy losses, and offers the advantage of connecting two EVs using the existing Type-2 charger ports, making it a flexible and practical solution for EV users.

For any V2V implementation, access to onboard instrumentation sensors and battery management system (BMS) controllers in both the provider and receiver EVs is crucial for enabling communication between the two vehicles and retrieving the necessary parameters for energy transfer. The bidirectional power converter interface for V2V charging is assumed to be available, provided that commercial EVs have integrated communication systems and access to controllers and instrumentation sensors.

The V2V mode selection depends on battery voltage levels, provider and receiver preferences, and user inputs, which are obtained through onboard instrumentation sensors. As shown in Figure 6, the onboard DSP controllers determine the appropriate mode of operation (e.g., forward step-up) and regulate the power flow direction and the required amount of energy transfer accordingly.

4. HARDWARE DESCRIPTION

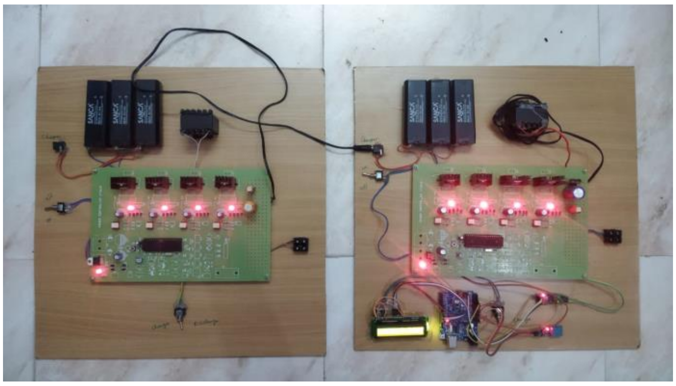

Fig. 3. Forward boost V2V mode

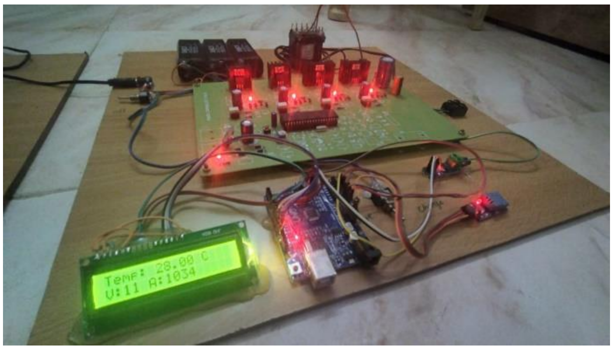

Fig. 4. Battery Charging level

MOSFET

The IRF840 is an N-Channel Power MOSFET capable of switching loads up to 500V and handling currents of up to 8A. It requires a gate threshold voltage of 10V between the Gate and Source terminals to activate. Due to its high gate voltage requirement, it cannot be directly connected to the I/O pin of a CPU. If a MOSFET with a lower gate voltage is required, options such as the IRF540N or 2N7002 can be considered. The IRF540N, with a lower gate threshold voltage of around 4V, is more suitable for low-voltage microcontroller-based switching applications. The 2N7002 is a small signal MOSFET with a gate threshold voltage of approximately 2V, making it ideal for low-power switching and logic-level applications.

MOSFETs play a crucial role in battery management systems (BMS) by acting as electronic switches for charging and discharging control. In electric vehicle applications, MOSFETs are used to regulate the flow of current between the battery and the load, ensuring efficient power delivery while protecting the battery from overcurrent conditions. A properly designed MOSFET switching circuit helps prevent overheating and improves the overall efficiency of the power system. Additionally, the use of high-performance MOSFETs enables precise control over power flow, which is essential for maintaining battery health and extending the lifespan of the battery pack.

PIC16F877

The PIC16F877 is a highly sophisticated microcontroller from Microchip, widely used for both modern and experimental applications due to its low cost, flexibility, high performance, and easy availability. It is ideal for use in machine control, measurement systems, and educational projects. The PIC16F877 features 40 pins and includes multiple input/output (I/O) ports, analog-to-digital converters (ADC), timers, and serial communication interfaces (SPI, I2C, and UART), making it suitable for complex automation and control systems. Its built-in EEPROM allows for data retention even after power loss, enhancing the reliability of applications.

In battery management systems, the PIC16F877 is used to monitor and control various parameters such as battery voltage, current, and temperature. It can interface with temperature sensors like the LM35 and voltage sensors to continuously measure the state of the battery pack. The LM35 temperature sensor provides an analog output proportional to the temperature, which the PIC16F877 converts into a digital signal using its ADC module. This enables real-time monitoring and protection against overheating or thermal runaway, which is critical for maintaining battery safety and performance.

Similarly, voltage sensors measure the battery's terminal voltage and provide feedback to the microcontroller. The PIC16F877 processes this data and adjusts the charging or discharging cycle accordingly. This ensures that the battery operates within safe limits, preventing overcharging or deep discharge, which could degrade battery health. Additionally, the microcontroller can trigger protective actions such as disconnecting the load or activating a cooling system if the measured values exceed preset thresholds. This integrated control system enhances the safety, efficiency, and lifespan of the battery pack, making the PIC16F877 a vital component in modern battery management systems.

5. SIMULATION DESIGN, SDG ADDRESSED & RESULTS

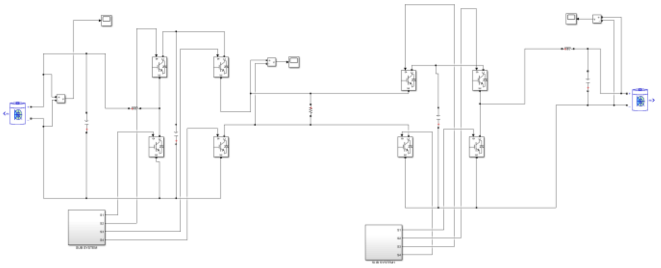

Figure 5.1: Overall Simulink model

The simulation model illustrates a peer-to-peer (P2P) Electric Vehicle (EV) charging system, enabling one EV to directly supply power to another. This approach is particularly useful for addressing emergency charging scenarios, especially in remote or isolated areas where traditional charging infrastructure is unavailable. The model is implemented using MATLAB/Simulink (version 2020b) to simulate realistic charging and power transfer conditions between the vehicles. In the simulation setup, both the donor and receiver EVs are equipped with 48V, 100Ah lithium-ion batteries, ensuring a practical balance between energy storage capacity, portability, and overall system efficiency. The 48V configuration is chosen for its suitability in managing high-power transfers while maintaining safety and reliability. The model also incorporates real-time monitoring of battery voltage and current levels to optimize the charging process and protect the battery from overcharging or deep discharge. Through this P2P charging method, the system enhances the feasibility of EV charging in off-grid or emergency situations, promoting greater flexibility and resilience in electric mobility.

Affordable and Clean Energy (SDG Goal 7): Electric Vehicle (EV) charging systems play a significant role in encouraging the widespread adoption of electric mobility, thereby reducing dependency on fossil fuels for transportation. By integrating clean energy sources such as solar and wind power into the charging infrastructure, EVs contribute to building a more sustainable and environmentally friendly energy ecosystem. The use of renewable energy for charging not only decreases greenhouse gas emissions but also promotes energy independence and long-term cost savings. Enhanced access to affordable EV charging stations powered by renewable sources supports the global shift toward cleaner transportation and aligns with the goal of increasing the proportion of renewable energy in the overall energy mix. This approach empowers consumers to transition to sustainable mobility solutions while fostering energy security and resilience in the transportation sector.

Climate Action (SDG Goal 13): Advanced EV charging infrastructure, particularly smart systems, is capable of seamlessly integrating with renewable energy sources such as solar panels and wind turbines. This facilitates efficient energy management and helps reduce the overall carbon footprint of transportation. Technologies like vehicle-to-grid (V2G) and vehicle-to-vehicle (V2V) power sharing enable bidirectional energy flow, allowing EVs to serve as mobile energy storage units that can supply power back to the grid during peak demand periods or provide emergency support in remote locations. This capability helps stabilize the energy grid, reduce reliance on conventional power generation, and support the transition toward a low-carbon economy. By leveraging smart charging solutions and renewable energy integration, EV infrastructure becomes a key driver of climate action, supporting a more sustainable and resilient global energy framework.

Figure 5.2: Input voltage

The output voltage consistently maintains a stable level at 90V, with minor variations of less than ±1% ripple. The system achieves rapid stabilization at 90V within just a few milliseconds, highlighting the effectiveness and precision of the converter's control mechanism.

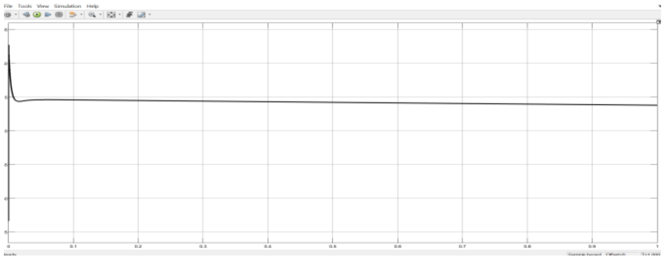

Figure 5.3: Buck mode

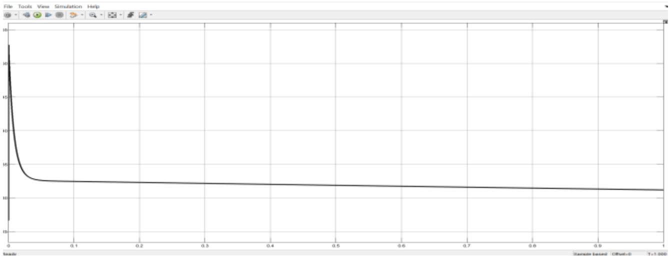

Figure 5.4: Boost mode

Similar to the 90V output, the 38V output remains steady with minimal ripple. This lower voltage level ensures safe and efficient charging for auxiliary systems. Although it stabilizes slightly slower than the 90V output, the control settings are deliberately tuned to be less aggressive, prioritizing safety and reliability.

6. CONCLUSIONS

This paper introduces a direct vehicle-to-vehicle (V2V) charging method that enables power transfer between two electric vehicles (EVs) without the need for external hardware or additional charging ports. This innovative approach provides a practical and effective emergency charging solution, especially in situations where AC grid access or DC fast-charging stations are unavailable. The proposed method allows for direct battery-to-battery connection through the onboard charger ports, significantly reducing the costs associated with additional hardware infrastructure. By bypassing redundant power conversion stages, the system improves overall efficiency and minimizes energy losses, enhancing the charging process's reliability and performance.

The direct V2V charging mechanism leverages the existing power architecture of the EV, ensuring compatibility without requiring any modifications to the vehicle's electrical design. This solution is particularly beneficial for addressing range anxiety among EV users, as it facilitates energy sharing between vehicles in remote or off-grid locations. The proposed system also enables cooperative energy exchange among EVs, promoting greater flexibility and resilience within the electric mobility ecosystem. The control algorithm used in the V2V charging system ensures stable power transfer, maintaining consistent voltage and current levels throughout the charging process.

Furthermore, the effectiveness and practicality of the proposed V2V approach are thoroughly validated through extensive MATLAB/Simulink simulations and a scaled experimental prototype. The simulation results demonstrate that the system achieves rapid stabilization with minimal voltage ripple, highlighting the accuracy and responsiveness of the control strategy. Experimental data further confirms the system’s ability to maintain high efficiency under varying load and environmental conditions. By eliminating the need for complex and expensive charging infrastructure, this direct V2V charging method provides a scalable and cost-effective solution for enhancing the accessibility and convenience of EV charging.

7. REFERENCES

[1] S. D. Vasconcelos et al., "Assessment of Electric Vehicles Charging Grid Impact via Predictive Indicator," in IEEE Access.

[2] Y. Tian et al., "Control Multiplexing and Switching Methods for Bi-Directional EV Chargers," 2024 International Conference on Energy and Electrical Engineering (EEE), Nanchang, China, 2024, pp. 1-7.

[3] J. Yang, G. C. Lim, C. Hwang and J. -I. Ha, "Two-Phase DC Charging Method for Improved Efficiency and Zero Torque in Motor-Integrated Charger," in IEEE Transactions on Industrial Electronics.

[4] H. Yang et al., "Optimization Scheduling Method for Electric Vehicle Charging and Swapping Stations Based on Elastic Load Regulation Potential," 2024 IEEE 2nd International Conference on Image Processing and Computer Applications (ICIPCA), Shenyang, China, 2024, pp. 1962-1966.

[5] K. Arulvendhan, S. K. Nagaratnam, R. Narayanamoorthi, A. H. Milyani, S. Alghamdi and M. Alruwaili, "Primary Side Hybrid Reconfigurable Compensation for Wireless EV Charging with Constant Current/Constant Voltage Control," in IEEE Access, vol. 12, pp. 149960-149976, 2024.

[6] P. Vinay, S. K. Suresh, V. D. Ganesh, T. V. Krishna, A. S. Ganesh and C. Saiprakash, "Design and Analysis of Rotor Technology for Electric Vehicle Application," 2023 International Conference on Power, Instrumentation, Energy and Control (PIECON), Aligarh, India, 2023, pp. 1-4.

[7] S. R and R. Manjunatha, "Design and Testing of an Integrated Electric Vehicle Model," 2021 IEEE

Mysore Sub Section International Conference (MysuruCon), Hassan, India, 2021, pp. 703-710.

[8] S. B. Kazeem Pasha and V. Champa, "Design and Development of Regenerative Suspension System for EV Applications," 2023 IEEE International Conference on Power Electronics, Smart Grid, and Renewable Energy (PESGRE), Trivandrum, India, 2023, pp. 1-5.

[9] M. H. S. M. Haram, M. T. Sarker, G. Ramasamy and E. E. Ngu, "Second Life EV Batteries: Technical Evaluation, Design Framework, and Case Analysis," in IEEE Access, vol. 11, pp. 138799-138812, 2023.

[10] V. P. Keseev, "Electric Bicycle Design Experiences and Riding Costs," 2020 7th International Conference on Energy Efficiency and Agricultural Engineering (EE&AE), Ruse, Bulgaria, 2020, pp. 1-4.