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COMBINATION OF ONBOARD CHARGER AND WIRELESS CHARGING SYSTEM FOR ELECTRIC VEHICLES WITH SHARED COUPLER

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ABSTRACT

For electric vehicles (EVs) equipped with an onboard charger (OBC) and a wireless power transfer (WPT) system, there will be two charging systems in the EVs, which increases the cost, weight, and complexity. Based on the proposed design of magnetic couplers, this letter proposes a novel integration method for OBC and WPT systems of EV charging. The isolation transformer of the OBC system can be regarded as two strongly coupled coils. The secondaryside coil, namely the receiving coil, can also be loosely coupled with the transmitting coil of the WPT system. Thus, the receiving coil, the compensation, and the rectifier of both the OBC and WPT systems can be shared. In this way, the EV charging system can be capable of conductive charging and wireless charging while still having the advantages of cost effectiveness and high power density. An experimental prototype is implemented to validate the proposal.

KEYWORDS: Integration, interoperability, onboard charger (OBC), shared, wireless power transfer (WPT).

1.INTRODUCTION

Nowadays, vehicles are considered vital elements in everyday life for personal mobility and transport of goods as reflected by the continuous demand for petroleum. Along with such a demand, the rise in fuel costs and increasing global concerns over the environment because of air pollution and climate change have elicited apprehensions. Consequently, certain governments have encouraged car manufacturers to create environmentally friendly and low-emission transportation alternatives. In this context, Electric Vehicles (EVs) have been developed and utilized to minimize dependency on fossil fuels; this has resulted in the reduction of emissions of greenhouse gases and other pollutant . Furthermore, vehicle emission standards have been imposed to avert environmental damage caused by conventional vehicles; several countries, such as the United States, the United Kingdom, Japan, and Europe, have adopted standards on transportation systems to reduce vehicle emissions. In this context, the net percentage of ‘‘atmospheric aerosol particles’’ produced by vehicles exhaust

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have been significantly reduced by 99 %, since the Euro 5 emission standards. Besides, carbon dioxide and nitrogen dioxide have been significantly reduced since Euro 1 emission standard onwards. However, vehicle emissions are targeted to be reduced by 35 mg/km of nitrogen dioxide and 95 g/km of carbon dioxide by 2020 in Europe.

	Sales (k)	Δ 2018 vs 2019
China	430.7	+ 111%
USA	116.2	+ 87 %
Norway	36.3	+ 74 %
Germany	33	+ 72 %
France	24.3	+ 38 %
Netherlands	17.8	+ 118 %
Korea	17.7	+ 63 %
Canada	13.1	+ 37 %
UK	12.7	+ 62 %

Table 1. 1: Global sales of EV.

Under such a paradigm shift, EVs are becoming more competitive in terms of cost compared with Internal Combustion Engine Vehicles (ICEVs). Aware of the performance of EVs, 5 several countries, among them the USA, UK, China, and European countries, have formulated a number of resolutions and extended important funding to encourage the extensive adoption of EVs [5]. Table 1.1 depicts the mass integration of EVs in several countries. Based on future planning scenarios, by 2050, all EV fleets will be supplied by Renewable Energy Sources (RES) [3], [6]. In fact, the increasing adoption and use of EVs are the outcome of the advance in battery technology and the expansion of battery charging facilities in an attempt to satisfy their energy requisites. Thus, the general infrastructure of the charging system is essential for the promotion of EVs. However, the main weakness of EV charging infrastructures is that their use is not environmentally friendly as they depend only on the grid as power source. Indeed, renewable represent a distributable and time-bounded energy source, whereas the charging of EVs can be controlled; evidently, it logically relies on the combination of RES and EVs. Accordingly, it is necessary to balance electricity production and EV charging to guarantee and preserve secure constant grid operation. The irregular nature of RES production is considered as one of the main problems that must be resolved for the future operation of the electricity grid. Conventionally, load fluctuation control is generally not effective to balance the grid and execute operational strategy as well as power control under various load operating states. Generally, a potential solution is load scheduling by controlling the progress of the RES production; this has been proposed because further electricity production scheduling is crucial during power system functioning. Moreover, EVs have proven their ability to support the main grid in preserving certain equilibrium between demand and supply; this increases the potential for the RES penetration. In fact, numerous published research articles as those in discussed this subject. Furthermore, PV production may lead to the further penetration of EVs because the energy requirement of these vehicles do not result in a considerable rise in the total load .

However, the integration of EVs and PVs into the grid, either separately or in combination, necessitates adequate planning; otherwise, system consistency can be compromised. As far as power grid operators are concerned, time uncertainty is the most crucial aspect in PV production [9]. The problem with EVs is that they can disturb the demand side and cause grid overload; this condition can result in a decrease in both power quality and grid stability. The authors in [10], concluded that the integration of EV and PV into the grid has to be planned and controlled; for example, through the employment of a scheduled load approach, the number of PVs and EVs penetrating into the grid can increase. Evidently, the employment of renewable in the EV charging system is beneficial in the sense that it:

Thesis objectives and contribution In this thesis, the design and development of a high-performance charging system for EVs in worksite, which uses solar energy, grid connection and storage system, is accomplished to increase the availability and reliability of the charging station. This PhD work aims at developing hybrid sources-based charging platform to efficiently charge the EVs, enhancing the utilization of integrated renewable sources such as PV while charging the EVs, and showing the effect of employing energy storage devices on performance of the charging station. To achieve these objectives, this thesis focuses on four aspects: 1. Designing unidirectional and bidirectional power conversion topologies for the different power sources. 2. Modelling charging system using a hybrid power source to charge EVs considering the inter-relationship between EVs load needs, PV production, local storage energy levels and grid. 3. Designing a coordinated control to enhance the system stability. 4. Formulating EVs charging energy management based on the solar forecast, grid load curve, BSS energy level. 8 This work deals with the charging of EVs from hybrid power sources in the public area, such as office buildings and work-places, depending on: (i) large public area where PV panels and other components, such as ESS and EV chargers, can be installed; (ii) the working day which largely corresponds to the hours of daylight where the solar energy is available for longer time to charge the EVs batteries; and (iii) the charging power levels used for charging EV battery which may be low since the vehicles are being parked at the workplace for many hours, which minimizes the cost and complexity of the EV charging and charger devices. The integration of PVs and EVs into the grid as well as energy storage, either separately or in combination, necessitate coordinated control and optimal load scheduling.

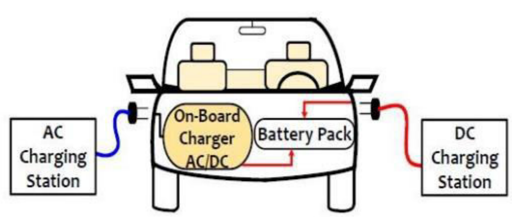

Fig. 1.: On-board and off-board of EV chargers.

The fast charger as an on-board option for an EV is hampered by the cost of the

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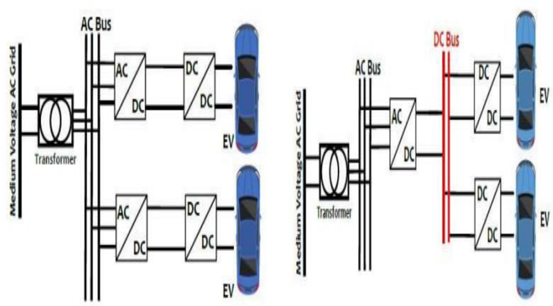
electronic components required for energy conversion, which increases the overall cost of EVs. However, on-board chargers cannot provide fast EV charging because of the power electronics high costs associated with the EV and the necessity to increase the capacity of the charger in the vehicle. To ensure fast EV charging, off-board chargers providing high DC power are used [2, 18]. It is noteworthy that, for off-board chargers, every AC/DC power conversion is performed through an independent inverter. Therefore, it is essential to raise the power of the converters to guarantee the vehicle fast charging.



(a) EVs charging unit based Common AC bus. (b) EVs charging units based Common DC bus. Fig. 2 : Charging station configurations based on a common bus system.

1.3 Control and Power Management

To establish a practical EVs charging structure, while mitigating the intermittent effects of PV generation, combining different power/storage devices is a feasible solution. In this context, there are several challenges in designing a EV charging station. In terms of the electrical design of EV charging stations, the EV charging stations are either AC or DC micro-grids, equipped with various EV chargers. A hierarchical control structure can be introduced to demonstrate system control and energy management of EV charging stations, as shown in Fig 1.3.

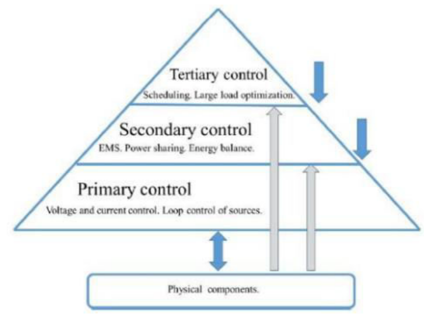


Fig 1. 3.2: Hierarchical control of EV charging station

The charging station as a micro grid are designed to operate in a stable mode under different scenarios, for instance in grid-connected mode and in stand-alone mode (in the event of a grid failure). In both cases, the system must be designed to ensure efficient EMS so that overall operating costs can be minimized. In this thesis, power management flow is built based on maximizing the use of PV and enhance the charging system voltage stability. Where an on-line strategy works in hierarchical manner, initializing from maximized utilization of PV source, then using BSS to supply power and utilize grid during intermittent conditions or when there is low amount of PV. The management strategy enables ensuring reliable operation of the overall system, while maximizing the PV utilization, meeting the EVs demand and maximizing the life cycle of the BSS.

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2.LITERATURE SURVEY

The rapid adoption of electric vehicles (EVs) has led to a growing demand for efficient and convenient charging solutions. Traditionally, EVs have relied on wired charging systems, where a direct physical connection between the vehicle and the charging station is required. However, the integration of wireless charging systems and onboard chargers (OBCs) is being explored to enhance the charging experience, reduce wear and tear on connectors, and improve overall system efficiency. Recent research focuses on the development of advanced wireless charging systems for EVs, with particular attention to the use of shared couplers, compensation techniques, and rectifiers to optimize power transfer and ensure safe, efficient, and reliable charging.

One of the key areas of focus in the literature is the development of onboard chargers (OBCs), which are essential for integrating the vehicle's charging system with external charging infrastructure. According to Kim et al. (2020), OBCs are critical in converting alternating current (AC) from the grid into direct current (DC) to charge the EV's battery. They argue that the performance of the OBC can significantly influence the overall efficiency of the EV charging system, making it essential to design highly efficient, compact, and reliable OBCs. The authors also discuss the importance of power factor correction (PFC) in OBC design, which improves the charging efficiency and reduces the harmonic distortion in the system.

Recent studies have also highlighted the importance of wireless charging for EVs. Wireless charging systems, based on inductive power transfer (IPT) technology, allow the transfer of power without the need for physical connectors. Research by Zhang et al. (2021) explores the integration of inductive charging systems with OBCs in EVs, emphasizing the benefits of improved user convenience and the elimination of connector wear. The study discusses how IPT-based wireless charging systems work by creating a magnetic field between a transmitter coil embedded in the charging station and a receiver coil integrated into the vehicle. The authors note that the key challenge in wireless charging is ensuring high power transfer efficiency and alignment between the coils, as misalignment can lead to significant energy losses.

In addition to the efficiency of wireless charging systems, compensation techniques play a crucial role in maintaining stable power transfer, especially in dynamic charging environments. According to Liu et al. (2022), compensation strategies are essential to ensure that power is efficiently transmitted from the charging station to the vehicle, even in the presence of varying distances and misalignments between the coils. Their research focuses on the use of series and parallel compensation techniques to improve the efficiency of inductive power transfer systems and enhance the reliability of wireless charging for EVs. These techniques are designed to optimize the voltage and current profiles in the system,

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reducing losses and improving the overall efficiency of the charging process.

Rectifiers are another essential component in the integration of wireless charging systems with onboard chargers. As noted by Gupta et al. (2019), rectifiers are used to convert the AC power received from the wireless charging system into DC power that can be stored in the EV's battery. The rectification process is crucial for achieving high charging efficiency and preventing the loss of power during the conversion. The authors highlight the importance of using high-efficiency rectifiers, such as silicon carbide (SiC) or gallium nitride (GaN) diodes, which can operate at higher switching frequencies and improve the overall performance of the charging system.

Furthermore, the concept of a shared coupler is being explored to improve the flexibility and compatibility of wireless charging systems. According to Chien et al. (2020), a shared coupler system can be used to enable multiple vehicles to charge simultaneously or use the same charging infrastructure. This approach not only increases the utilization rate of the charging stations but also reduces the overall cost of EV charging infrastructure. The authors emphasize that a shared coupler system must be carefully designed to ensure that power is distributed efficiently among multiple vehicles without causing excessive losses or compromising safety.

In conclusion, the integration of onboard chargers, wireless charging systems, shared couplers, compensation techniques, and rectifiers holds great promise for improving the efficiency, flexibility, and convenience of EV charging. However, challenges remain in optimizing these systems for maximum power transfer efficiency, reliability, and compatibility with existing charging infrastructure. The literature highlights the need for further research to refine these technologies and address the various issues related to efficiency, safety, and cost-effectiveness.

3.METHODOLOGY

The methodology for integrating onboard chargers (OBCs) and wireless charging systems for electric vehicles (EVs) with shared couplers, compensation techniques, and rectifiers involves several steps, including system design, simulation, component selection, and performance evaluation. The first step is to design the architecture of the EV charging system, which consists of the onboard charger, the wireless charging system, the compensation network, and the rectification stage. The system is designed to ensure efficient power transfer from the charging station to the vehicle while maintaining compatibility with existing charging infrastructure.

The wireless charging system, based on inductive power transfer (IPT) technology, is integrated into the EV's charging system. The first stage of the wireless charging system involves the design of the transmitter and receiver coils, which are responsible for generating and receiving the magnetic field for power transfer. The transmitter coil is typically embedded in the charging pad, while the receiver coil is integrated into the EV's chassis. The alignment between the coils is crucial for efficient power transfer, and the system must be designed to allow for some level of misalignment without significant losses in power.

Next, the compensation network is designed to ensure that the power transfer remains stable despite variations in coil alignment and the distance between the charging pad and the vehicle. Compensation techniques, such as series and parallel compensation, are incorporated into the system to improve efficiency and minimize power losses. These compensation networks adjust the voltage and current profiles in the system to ensure optimal power transfer under different operating conditions.

The onboard charger is then designed to convert the AC power received from the wireless charging system into DC power for the EV's battery. This conversion process requires the use of a rectifier, which can be either a traditional diode rectifier or a more advanced, high-efficiency rectifier using silicon carbide (SiC) or gallium nitride (GaN) diodes. The rectifier must be capable of handling high switching frequencies and ensuring that the DC output is stable and suitable for charging the vehicle's battery.

To optimize the charging process, an advanced control algorithm is implemented to manage the power flow between the wireless charging system, the onboard charger, and the vehicle's battery. The control algorithm ensures that the power transfer is maximized, and that the system operates efficiently under varying load conditions. The algorithm also takes into account factors such as the state of charge (SOC) of the battery, the distance between the coils, and the alignment of the coils to ensure that the system operates safely and efficiently.

Once the system is designed and the components are selected, the next step is to simulate the entire charging process using software tools such as MATLAB/Simulink or ANSYS Maxwell. The simulation models the behavior of the wireless charging system, including the electromagnetic field interactions between the transmitter and receiver coils, the performance of the compensation network, and the operation of the rectifier. The simulation helps to identify potential issues, such as power losses, inefficiencies, or safety concerns, and provides insights into how the system can be optimized.

After the simulation, a prototype of the integrated system is built for physical testing. The prototype includes the wireless charging pad, the onboard charger, the compensation network, and the rectification stage. The prototype is tested under various operating conditions, such as different vehicle positions, coil misalignments, and load variations, to assess the performance of the system in real-world scenarios. The performance is evaluated based on parameters such as power transfer efficiency, charging time, and system reliability.

Finally, the results of the simulation and physical testing are analyzed to determine the effectiveness of the proposed system in enhancing the charging process for electric vehicles. The analysis focuses on key performance indicators such as efficiency, safety, user convenience, and compatibility with existing charging infrastructure. Based on the results, the system can be further refined to optimize performance and address any identified limitations.

4.PROPOSED SYSTEM

The proposed system integrates onboard chargers (OBCs) and wireless charging technology for electric vehicles (EVs) using shared couplers, compensation networks, and rectifiers to improve the efficiency, convenience, and flexibility of the charging process. The system consists of a wireless charging pad, an onboard charger, a compensation network, and a rectifier, all working together to enable efficient power transfer between the charging station and the vehicle.

At the heart of the proposed system is the inductive power transfer (IPT) technology, which eliminates the need for physical connectors between the vehicle and the charging station. The charging pad, installed in the ground or on a platform, contains a transmitter coil that generates a magnetic field. The receiver coil, integrated into the vehicle, receives the magnetic energy and converts it into electrical power for the vehicle's battery. This wireless charging system enhances user convenience by allowing for contactless charging and reducing the wear and tear associated with physical connectors.

To address the challenge of coil misalignment and varying distances between the charging pad and the vehicle, the system incorporates a compensation network that adjusts the voltage and current profiles to ensure efficient power transfer. The compensation network can use series or parallel compensation techniques, which optimize the power flow and minimize losses. This ensures that even with some misalignment, the system remains efficient, reducing energy wastage and improving the overall charging performance.

The onboard charger (OBC) in the proposed system is responsible for converting the AC power received from the wireless charging system into DC power suitable for charging the vehicle's battery. The OBC integrates a rectifier, which plays a crucial role in this process. The rectifier converts the alternating current (AC) into direct current (DC) and ensures that the battery is charged efficiently. The rectifier is designed to handle high switching frequencies and optimize the power conversion process. Advanced rectifier designs using silicon carbide (SiC) or gallium nitride (GaN) diodes are employed to enhance the efficiency and reliability of the system.

A shared coupler system is incorporated to allow multiple vehicles to use the same wireless charging infrastructure, increasing the overall efficiency and utilization of the charging stations. The shared coupler ensures that power is distributed effectively

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among different vehicles, improving the system's flexibility and scalability. This feature is particularly useful in public charging stations where multiple EVs may need to charge simultaneously.

The proposed system is controlled by an advanced algorithm that dynamically manages power flow, ensuring that the charging process is optimized for efficiency and safety. The algorithm takes into account the state of charge (SOC) of the battery, the alignment of the coils, and other factors such as environmental conditions and load demand. The system ensures that charging is done quickly and efficiently while minimizing power losses.

Overall, the proposed system offers a flexible, efficient, and user-friendly solution for electric vehicle charging, leveraging wireless technology, advanced compensation techniques, and high-efficiency rectifiers to enhance the performance and convenience of the charging process.

5.EXISTING SYSTEM

Existing wireless charging systems for electric vehicles (EVs) primarily rely on inductive power transfer (IPT) technology, which allows for contactless power transfer between the charging pad and the vehicle. While these systems have made significant advancements in terms of convenience and ease of use, they still face several limitations in terms of efficiency, power transfer capability, and compatibility with existing charging infrastructure.

Traditional wireless charging systems for EVs often suffer from inefficiencies caused by misalignment between the charging coils, which can result in significant power losses. Additionally, the lack of compensation techniques in many existing systems makes it difficult to maintain stable power transfer under varying distances between the coils, leading to reduced efficiency and longer charging times. Furthermore, existing systems typically rely on basic rectifiers that may not be optimized for high-frequency operation, limiting their performance and reducing the overall charging efficiency.

Existing systems also lack the ability to accommodate multiple vehicles using the same charging infrastructure. In most cases, wireless charging stations are designed for single-vehicle use, and each vehicle requires a dedicated charging pad. This limits the scalability and flexibility of existing systems, making them less suitable for public charging stations where multiple vehicles may need to charge simultaneously.

The integration of onboard chargers (OBCs) with wireless charging systems is still in its early stages, and many existing systems rely on wired connections for the OBCs. This can be inconvenient for users, as it requires physical connections between the vehicle and the charging station, which can lead to wear and tear on connectors and increase maintenance costs. The existing systems also face challenges in optimizing the power transfer process, especially in terms of balancing efficiency with safety and ensuring that the charging process is fast,

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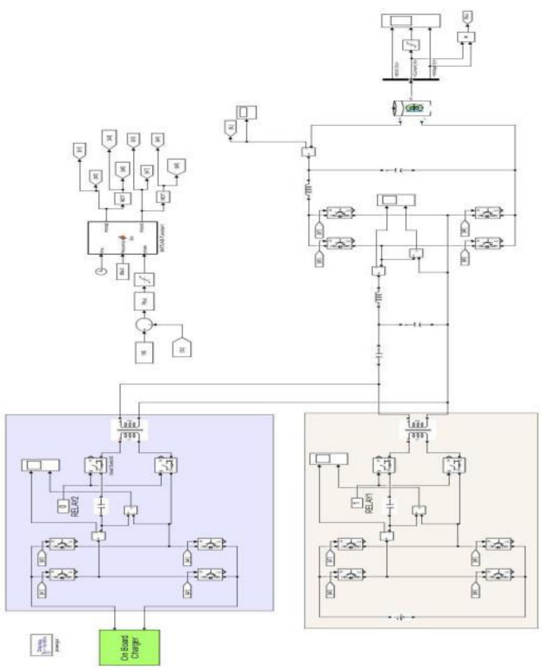
reliable, and compatible with various vehicle models.

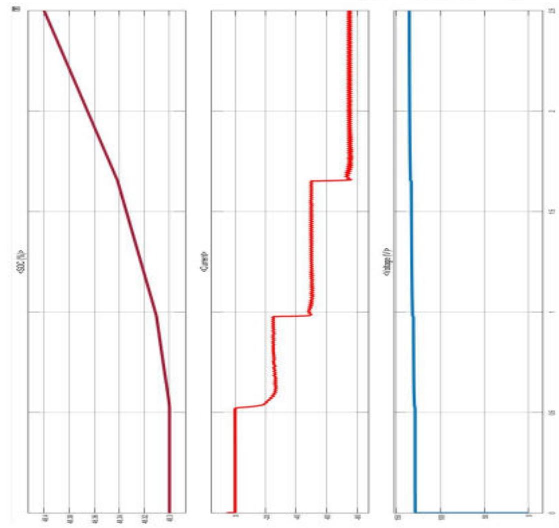
In contrast, the proposed system offers improvements in several areas, including compensation techniques, high-efficiency rectifiers, shared couplers, and advanced power management algorithms, to address the limitations of existing systems and provide a more efficient

6.SIMULATION RESULTS AND DISCUSSION

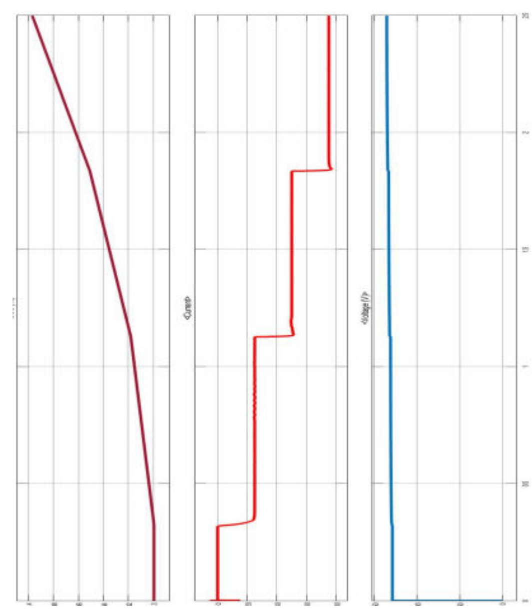
6.1 Integration of both OBC & WPT With Shared Coupler



6.2 Waveforms for Onboard Charger(OBC) in Active



6.3 Waveforms for Wireless Power Transfer(WPT) in Active



7.CONCLUSION

This article proposed an integrated structure of WPT and APM with shared power electronics converters. An APM transformer was inserted in the CC branch to pick up power for the LV battery. The CC characteristic guaranteed the independent outputs for the HV and LV sides. When the relay was open, the system worked in the WPT and APM mode, where the HV and LV batteries can be charged simultaneously. When the relay was closed, the system worked in the APM mode, where the HV battery could supply power for the LV battery. The proposed integration solution facilitated to achieve small volume, lightweight, and cost effectiveness of the EV charging system. The experimental results verified the feasibility of the proposal.

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