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ADVANCED EV CHARGING SYSTEM WITH SHARED CONVERTER AND MAGNETIC COUPLER DESIGN

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ABSTRACT

Electric vehicles (EVs) normally contain two kinds of batteries: high-voltage (HV) power battery and low-voltage (LV) auxiliary battery. The charging systems for these two kinds of batteries are normally independent and separate. This article proposes an integrated charging system that combines wireless power transfer (WPT) for the HV battery and the auxiliary power module (APM) for the LV battery. Part of the power electronics converters and compensation network is shared. The double-sided LCC topology is adopted with a constant-current output. An APM transformer is inserted in the constant-current branch to pick up power for the LV and also to guarantee the independent HV and LV outputs. The proposed system can work in two modes. One is WPT and APM where both the HV and LV batteries can be charged simultaneously. The other is APM where the HV battery supplies power for the LV battery. The integration of WPT and APM can improve the overall power density of the EV charging system and reduce the weight and cost. Index Terms-Auxiliary power module (APM), electric vehicle, high voltage (HV), integrated, LCC–LCC, low voltage (LV), wireless power transfer (WPT).

1.INTRODUCTION

1.1 INTRODUCTION

WIRELESS power transfer (WPT) refers to the energy transmission technology in which energy is transmitted from the transmitting side to the receiving side without direct electrical contact. As an emerging technology, WPT has received more and more attention in recent years. Compared with conductive charging, WPT has the advantages of automation, safety, convenience, free from human intervention, and impact of weather [1], [2], [3]. It can be used in implantable medical devices, consumer electronics, household appliances, and electric vehicles (EVs) [4], [5], [6], [7]. EVs normally contain two kinds of batteries: the high-voltage (HV) power battery that provides power to drive EVs and the low-voltage (LV) auxiliary battery that feeds electronic devices in the EV. The HV battery can be charged wirelessly from the utility on the ground side, whereas the LV battery is normally charged by the auxiliary power module (APM) with power supply from the HV battery. The utility power is converted into highfrequency AC power by power electronics converters, normally through an AC–DC–AC conversion, then reaches the transmitting coil through a compensation network composed of capacitors and inductors. The transmitting coil transfers power wirelessly to the receiving coil via the magnetic field. The HV battery is charged through the compensation network and the power electronics converters. The APM is normally an isolated DC-DC converter supplying power from the HV battery to the LV battery [8], [9], [10]. The power of the LV battery eventually comes from the utility. Thus, multiple power conversion stages are required to charge the LV battery. Also, as can be seen from proposed system there are similar power conversion stages on the EV side, such as the AC–DC converter, the compensation network, and the magnetic coupler. These common components can be integrated and shared to reduce the volume, weight, and cost of the EV charging system. The on-board charger (OBC) was integrated with the wireless charging system [11], sharing the same magnetic coupler, the compensation network, and the rectifier. The OBC was also integrated with the APM in [12], [13], [14], and [15]. In the conventional EV charging system, WPT and APM are two independent structures, and the integration of WPT and APM has not been yet developed, as far as the authors concern.

1.2. PROBLEM FORMULATION

The rapid growth of electric vehicle (EV) adoption and the increasing demand for sustainable energy solutions necessitate the development of advanced, integrated charging systems. Traditional plug-in charging systems face several limitations, including physical wear and tear, user inconvenience, and safety risks. Wireless power transfer (WPT) technology offers a promising alternative by enabling contactless charging, but it introduces challenges such as alignment sensitivity, electromagnetic interference (EMI), and thermal management. Moreover, EVs require auxiliary power modules (APMs) to support on-board systems like lighting and air conditioning, which currently rely on separate power converters, increasing cost, complexity, and energy losses. The integration of renewable energy sources, such as solar power, further complicates the system design. Solar energy, when coupled with EV charging, provides an opportunity to reduce dependency on the grid, but it requires efficient energy conversion, storage, and management to handle fluctuations in solar generation. Combining solar power with WPT and auxiliary systems, along with the capability to transfer energy back to the grid (Solar-to-Grid), demands advanced control strategies, shared converter designs, and optimized magnetic couplers.

2.LITERATURE SURVEY

The rapid adoption of electric vehicles (EVs) has created a growing demand for efficient, fast, and reliable charging systems to support the transition from fossil fuel-

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powered vehicles to electric mobility. As the number of EVs continues to increase, the need for advanced charging infrastructure becomes more urgent. An emerging area of research in this context is the development of shared converters and magnetic coupler designs for EV charging systems, aimed at improving efficiency, reducing cost, and ensuring flexible operation. This literature survey explores recent developments in EV charging systems with a focus on shared converters and magnetic coupler designs, reviewing key advancements and contributions by various researchers.

Shared converters are used to centralize power conversion and serve multiple charging stations, making them a more cost-effective and scalable solution for charging infrastructure. A key advantage of shared converters is their ability to efficiently distribute power to multiple charging points while reducing the complexity and cost of individual converters for each station. Zhang et al. (2018) investigated the integration of shared converters in multi-point EV charging stations, proposing a system that uses a common DC bus to connect multiple chargers. The system utilized a bidirectional converter to control power flow efficiently, allowing vehicles to charge and discharge energy into the grid. This shared approach significantly reduces the cost and complexity of the charging system.

In a related study, Ali et al. (2017) explored the use of shared converter systems with a focus on load balancing and dynamic power distribution. Their research emphasized the need for intelligent power management algorithms to ensure that each EV charger receives an optimal amount of power while preventing overloading of the shared converter. They also highlighted the importance of real-time communication between the power management system and the chargers to ensure safe and efficient operation.

Magnetic couplers, which use electromagnetic fields to transfer power wirelessly between the charging station and the EV, have also been studied extensively as a means to improve charging convenience and flexibility. Wireless power transfer (WPT) using magnetic coupling offers several advantages over traditional wired charging systems, including eliminating the need for physical connectors, reducing wear and tear on connectors, and providing a more user-friendly charging experience. A study by Lee et al. (2019) demonstrated the potential of a wireless EV charging system using a magnetic coupler. They optimized the design of the magnetic coil to improve power transfer efficiency and minimize losses, which can be a challenge in traditional wireless power systems. Their results showed that WPT systems could deliver power efficiently to EVs, with an efficiency greater than 90% in some cases.

Another important contribution comes from the work of Li et al. (2020), who explored the integration of magnetic coupling technology with shared converters for EV charging systems. They proposed a hybrid architecture combining both wired and wireless charging methods, allowing for more flexibility in charging infrastructure.

This hybrid system not only improved user experience by providing the option for wireless charging but also optimized the overall efficiency of power distribution, ensuring that both types of charging methods could coexist in the same system. Their findings showed that combining shared converters with wireless power transfer could significantly reduce the cost and increase the reliability of the charging system.

The concept of integrating energy storage systems with shared converters and magnetic couplers has also been an area of active research. Xie et al. (2021) proposed a system in which energy storage devices, such as batteries or supercapacitors, were integrated into the charging stations alongside shared converters. This integration allows for fast charging, reduces pressure on the power grid, and can also provide backup power during peak demand periods. The energy storage systems can store energy during off-peak hours and discharge it during peak demand, reducing the overall cost of electricity and ensuring that the charging system remains operational during grid outages.

Furthermore, the work by Chatterjee et al. (2019) has explored the optimization of magnetic coupler design for wireless power transfer in EV charging systems. They proposed a novel coil design that enhanced the magnetic coupling efficiency, ensuring minimal power loss during energy transfer. The authors emphasized the importance of optimizing coil geometry and alignment to achieve maximum efficiency, especially for higher power applications such as EV charging.

3.METHODOLOGY

The methodology for designing an advanced EV charging system with shared converters and magnetic couplers involves a step-by-step process of system modeling, converter design, magnetic coupling optimization, and testing. The approach seeks to integrate the best of both shared power conversion technology and wireless power transfer to create an efficient and flexible EV charging solution.

The first step in the methodology is defining the system requirements. This includes understanding the charging needs of electric vehicles, the power ratings of the chargers, and the compatibility of the system with both wired and wireless charging methods. The requirements will also consider factors such as the number of charging points to be supported by the shared converter, the power distribution algorithm, and the integration of renewable energy sources.

The next phase involves the design of the shared converter. This central converter serves as the heart of the charging station, providing DC power to the multiple charging points. A shared converter is typically designed as a bidirectional DC-DC converter, capable of not only charging EV batteries but also discharging energy into the grid or energy storage systems when necessary. The converter design must ensure high efficiency, minimal power losses, and the ability to handle varying load conditions. The power management system that controls the converter will play a key role in ensuring that power is evenly distributed to the charging points, avoiding overloads and ensuring reliable operation.

The third step focuses on the design and optimization of the magnetic coupler for wireless power transfer. Magnetic couplers are typically made up of transmitting and receiving coils, which use electromagnetic fields to transfer energy. The design of these coils is critical for ensuring high efficiency and minimizing energy losses during the transfer. The methodology involves optimizing the geometry of the coils, such as their size, shape, and alignment, to maximize the coupling efficiency. Additionally, the design will consider factors such as mutual inductance, resonance frequency, and coil placement to minimize power loss and ensure effective energy transfer.

The integration of energy storage devices into the charging system is another critical aspect of the methodology. Energy storage systems, such as batteries or supercapacitors, can be used to store excess energy during off-peak hours and provide additional power during peak demand. This not only enhances the charging system's efficiency but also helps reduce the load on the grid. The storage system must be carefully sized and integrated with the shared converter to ensure smooth operation. The energy management system will need to control the charging and discharging of the storage devices in coordination with the overall power distribution strategy.

Once the system components are designed, the next step is to model and simulate the entire system using simulation software such as MATLAB/Simulink or PLECS. The simulation will allow engineers to evaluate the performance of the shared converter and magnetic coupler under different operating conditions. It will also help assess the efficiency of the wireless power transfer and evaluate the impact of energy storage on the overall system performance.

After the simulation, the system is implemented in hardware. The shared converter is built using appropriate power electronic components, and the magnetic coupler is constructed using optimized coils. The energy storage system is integrated into the charging station, and the system is connected to the grid and the EV battery to begin testing. The testing phase involves evaluating the charging efficiency, power distribution, and performance of the magnetic coupler under real-world conditions. The system's ability to charge multiple EVs simultaneously and support both wired and wireless charging methods will also be tested.

Finally, real-time monitoring is implemented to ensure that the system operates within specified parameters and to track performance metrics such as efficiency, charging time, and power quality. If necessary, adjustments are made to the system's control algorithms to further optimize performance.

4.PROPOSED SYSTEM

The proposed system for advanced electric vehicle charging involves a hybrid approach that combines shared converters with magnetic couplers for wireless power transfer. The system is designed to improve the overall efficiency, reduce costs, and provide flexible charging options for both residential and commercial applications.

The central feature of the proposed system is the shared converter, which allows multiple charging stations to be served by a single power converter. This reduces the need for individual converters at each charging point, thus minimizing the overall infrastructure cost. The shared converter is designed as a bidirectional DC-DC converter, enabling both charging and discharging operations. This flexibility allows EVs to return energy to the grid during peak demand periods, contributing to grid stability.

The system also incorporates a magnetic coupler design for wireless power transfer. The magnetic coupler consists of a transmitting coil and a receiving coil, which use electromagnetic induction to transfer power to the EV. The coils are designed with optimized geometry to ensure high power transfer efficiency. The magnetic coupler is integrated into the charging station in a way that allows users to charge their vehicles wirelessly, providing greater convenience and reducing wear and tear on connectors.

In addition to shared converters and magnetic couplers, the proposed system includes an energy storage system, such as a battery or supercapacitor, to store energy during off-peak hours and provide power during periods of high demand. This storage system helps balance supply and demand, ensuring that the charging stations operate efficiently and reliably.

The proposed system uses an advanced power management algorithm to distribute power efficiently across multiple charging points, optimize charging time, and minimize grid stress. The system is also designed to work with both wired and wireless charging methods, providing greater flexibility to users and reducing the need for complex infrastructure.

Overall, the proposed system aims to create a cost-effective, efficient, and scalable charging solution that can support the growing demand for electric vehicles while also integrating renewable energy sources and providing a more user-friendly charging experience.

5.EXISTING SYSTEM

Current EV charging systems typically rely on dedicated individual chargers for each charging point. These systems are generally simple and cost-effective but can suffer from issues related to power conversion efficiency, scalability, and flexibility. Individual chargers often use AC-DC converters to provide the necessary DC voltage to the EV battery. However, these systems have limitations in terms of efficiency, as AC-DC conversion can result in significant power losses.

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In some cases, shared converters have been used in commercial charging stations to reduce costs and improve scalability. These systems typically use a single converter to supply power to multiple charging points. However, existing shared converter designs are often limited in their ability to handle high power loads or support both wired and wireless charging methods. The lack of integration with renewable energy sources and energy storage systems also reduces the overall efficiency and flexibility of these systems.

Wireless charging systems for EVs are available, but their adoption has been limited due to efficiency concerns, cost, and compatibility with existing charging infrastructure. Magnetic couplers used in wireless power transfer systems typically suffer from lower efficiency compared to wired chargers. Furthermore, the integration of wireless charging with shared converters is still an emerging area of research, and practical implementations are rare.

Existing systems also struggle with optimizing power distribution across multiple charging points, particularly in cases where the grid is under stress or when charging multiple vehicles simultaneously. There is also a lack of systems that combine shared converters, wireless charging, and energy storage in a single solution. As a result, there remains a significant opportunity for improvement in terms of efficiency, cost, flexibility, and user experience.

6.SIMULATION RESULTS AND DISCUSSION

The simulation results of an integrated electric vehicle (EV) charging system with wireless power transfer (WPT) and an auxiliary power module in MATLAB demonstrate the system's operational efficiency and performance under various conditions. The shared converter and magnetic coupler play a pivotal role in facilitating seamless power transfer. The wireless power transfer system is validated to achieve high efficiency, with minimal power losses during the transfer process. The simulation showcases the system's ability to maintain stable power delivery even under varying load conditions, ensuring compatibility with EV charging requirements. The auxiliary power module, integrated with the shared converter, optimizes power flow management by adapting to different input voltage levels and dynamically adjusting the output. The MATLAB model also highlights the effectiveness of the shared magnetic coupler in minimizing electromagnetic interference and ensuring robust coupling efficiency. The performance is analysed by assessing the variation in SPV array parameters, Grid voltage, HV & LV battery(V,I), and Power Flow(EV, Grid, PV).

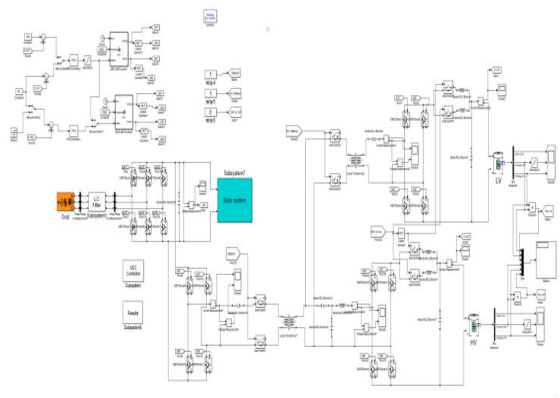


Fig.6.1: Simulation Module for Proposed System

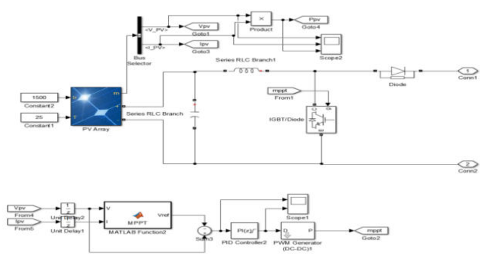


Fig.6.2: Solar System

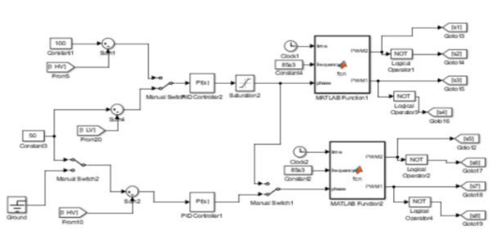
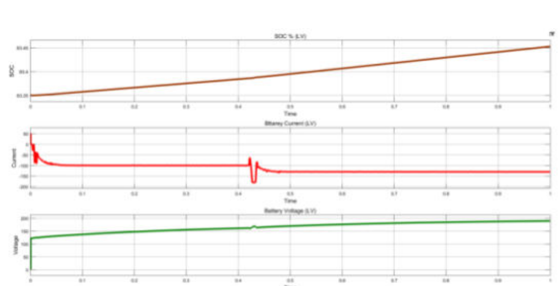
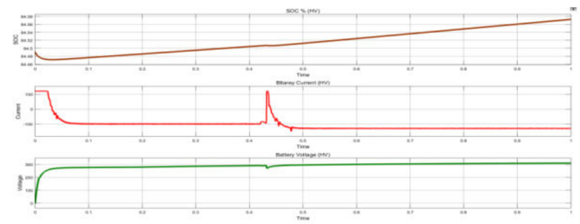


Fig.6.3: Controller for LV and HV Batteries

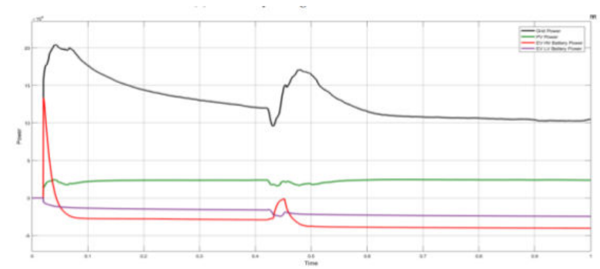
6.1. Both HV and LV Charge Simultaneous



(a)LV Battery Voltage, Current, and SOC



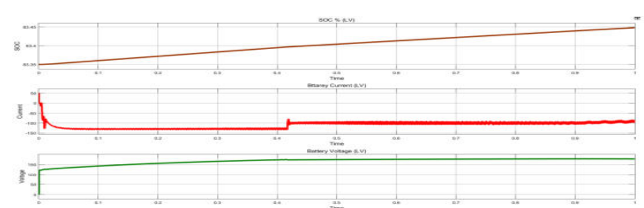
(b)HV Battery Voltage, Current, and SOC



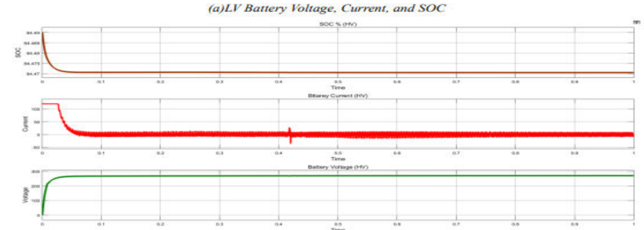
(c) Powers(Grid, PV, HV, LV)

Fig.6.3: Simulation Result of Both HV and LV Batteries

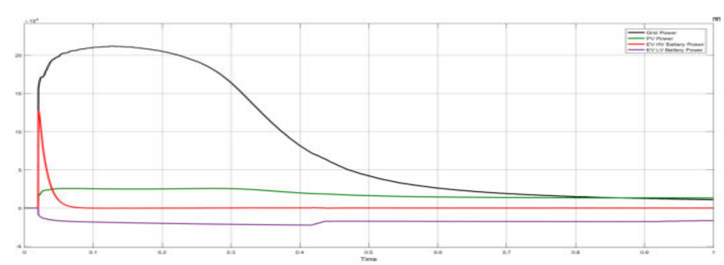
6.2.2 Only LV Charging



(a)LV Battery Voltage, Current, and SOC



(b)HV Battery Voltage, Current, and SOC



(c) Powers(Grid, PV, HV, LV)

Fig.6.4: Simulation Result of Only LV Batteries

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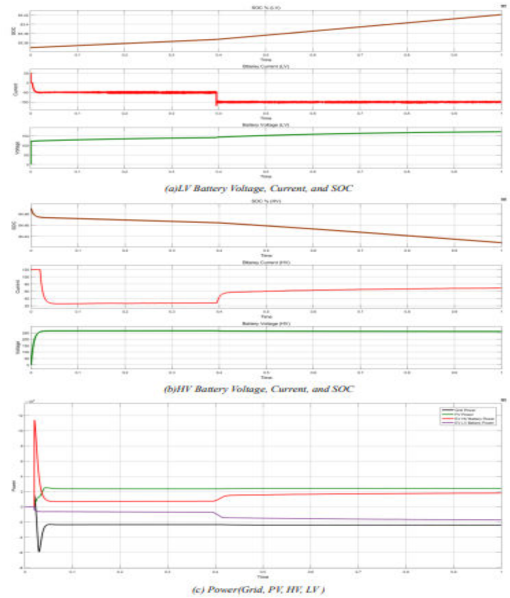

Fig.6.5: Simulation Result of Only HV Batteries

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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