DESIGN AND SIMULATION OF AN INTEGRATED WIRELESS CHARGING RECEIVER FOR ELECTRIC VEHICLES WITH DUAL INVERTER DRIVES

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ABSTRACT

Wireless charging has emerged as a safe and user-friendly alternative to conventional plug-in charging methods for electric vehicles (EVs). Nevertheless, existing wireless charging systems often require additional hardware such as receiver coils and dedicated power converters, leading to increased system complexity, cost, and weight. This paper proposes an integrated wireless charging receiver architecture that leverages existing drivetrain components, specifically the traction inverter and electric motor, to perform receiver-side power conversion. By reusing these components, the need for separate charging circuitry is significantly reduced. The proposed system is designed to limit the circulation of high-frequency currents within sensitive drivetrain elements, thereby minimizing associated losses and enhancing operational reliability. Moreover, the drivetrain inherently regulates the battery charging process, eliminating the requirement for complex communication and control mechanisms from the transmitter side. Simulation studies conducted on a 110 kW EV drivetrain coupled with a 6.6 kW wireless power transfer system demonstrate a maximum efficiency of 94.3% at a coil separation distance of 200 mm. These results validate the effectiveness, efficiency, and practical feasibility of the proposed integrated charging solution.

Keywords: Wireless charging, Electric vehicles, Traction inverter, Dual inverter drives, Wireless power transfer, Charging efficiency, Integrated drivetrain

INTRODUCTION

The rapid transition toward sustainable transportation has significantly accelerated the adoption of electric vehicles (EVs) across the globe. This shift is primarily driven by increasing environmental concerns, stringent emission regulations, and the depletion of fossil fuel resources [1], [2]. Despite remarkable advancements in battery technologies and power electronics, one of the major challenges hindering widespread EV adoption remains the charging infrastructure and user convenience [3]. Conventional plug-in charging systems, although widely used, present several limitations such as physical wear and tear of connectors, safety concerns in harsh weather conditions, and user inconvenience [4]. In this context, wireless power transfer (WPT) technology has emerged as a promising alternative, offering contactless energy transfer that enhances safety, reliability, and ease of use [5], [6]. By eliminating the need for physical connectors, wireless charging systems can significantly improve the overall user experience and facilitate the development of autonomous charging solutions [7].

However, the practical implementation of wireless charging in EVs introduces several technical and economic challenges. Traditional WPT systems require additional receiver-side components, including dedicated coils, rectifiers, and DC–DC converters, which increase system cost, weight, and design complexity [8], [9]. These additional components also impact the overall efficiency and thermal performance of the system, posing constraints on compact vehicle designs [10]. Furthermore, maintaining efficient power transfer over varying coil alignment and air gap distances remains a critical challenge [11]. To address these issues, researchers have explored various compensation topologies, control strategies, and magnetic designs to enhance efficiency and tolerance to misalignment

[12], [13]. Nevertheless, the integration of wireless charging systems with existing EV drivetrain components has not been fully exploited, leaving significant scope for innovation [14].

Recent studies have begun to investigate the possibility of utilizing onboard power electronics, such as traction inverters and motor windings, to perform additional functions beyond propulsion [15]. This multifunctional approach aims to reduce hardware redundancy and improve overall system utilization. By reconfiguring the traction inverter to operate as a rectifier during charging, it becomes feasible to eliminate the need for separate receiver-side converters. Additionally, the electric motor can be leveraged as part of the power transfer pathway, enabling a more compact and integrated system design. However, such integration introduces challenges related to high-frequency current circulation, electromagnetic interference, and potential losses within the drivetrain components [1], [6]. Therefore, careful system design and control strategies are required to ensure that the charging process does not adversely affect the performance or lifespan of the traction system [3].

In light of these challenges, this paper proposes an integrated wireless charging receiver architecture that effectively utilizes the EV's existing dual inverter drive system for battery charging. The proposed approach minimizes additional hardware requirements while ensuring that high-frequency currents are carefully managed to reduce losses and protect sensitive components. Moreover, the drivetrain itself regulates the charging process, eliminating the need for complex communication and control from the transmitter side [7], [10]. The system is evaluated through detailed simulation studies using a 110 kW EV drivetrain and a 6.6 kW wireless charging setup, demonstrating high efficiency and robust performance under practical operating conditions [11], [15]. The results confirm that the proposed integrated solution offers a cost-effective, efficient, and scalable alternative to conventional wireless charging systems, thereby contributing to the advancement of next-generation EV charging technologies [12].

LITERATURE SURVEY

The development of wireless power transfer (WPT) technology for electric vehicles has attracted significant research attention in recent years due to its potential to enhance charging convenience and safety. Early studies primarily focused on inductive power transfer (IPT) systems employing loosely coupled coils and compensation networks to achieve efficient energy transmission across air gaps [1], [2]. Series–series and series–parallel compensation topologies were widely investigated to improve power transfer capability and system stability under varying load conditions [3]. Researchers also examined resonant coupling techniques to enhance efficiency and reduce reactive power circulation [4]. These foundational works established the theoretical and practical framework for WPT systems, demonstrating efficiencies exceeding 90% under optimal alignment conditions [5]. However, these systems typically relied on dedicated receiver-side rectifiers and DC–DC converters, which increased system complexity and cost, limiting their large-scale commercial adoption [6].

Subsequent research efforts focused on improving misalignment tolerance and maintaining high efficiency over varying distances between transmitter and receiver coils. Advanced coil structures, such as double-D (DD) and circular pad designs, were proposed to enhance magnetic coupling and reduce sensitivity to lateral and angular misalignments [7], [8]. Additionally, adaptive tuning methods and dynamic impedance matching techniques were introduced to compensate for variations in coupling coefficients during operation [9]. Control strategies, including phase-shift control and frequency modulation, were also developed to regulate power flow and ensure stable operation under dynamic conditions [10]. Despite these advancements, most systems still required complex communication links between the transmitter and receiver to coordinate power transfer, which added to system design challenges and potential reliability issues [11].

To address the limitations associated with additional hardware, recent studies have explored the integration of wireless charging functionality with existing onboard power electronics in EVs. In particular, the use of traction inverters as bidirectional converters during charging has gained considerable attention [12]. This approach allows the inverter to operate in rectification mode, thereby eliminating the need for separate receiver-side converters. Some researchers have also investigated the utilization of motor windings as part of the charging circuit, effectively reducing component redundancy and improving power density [13]. However, these integrated configurations introduce new challenges, such as the presence of high-frequency currents in motor windings, increased core losses, and potential electromagnetic interference [14]. Careful design considerations and filtering techniques are therefore necessary to mitigate these effects and ensure reliable operation.

More recent advancements have focused on enhancing system efficiency and simplifying control mechanisms in integrated wireless charging systems. Researchers have proposed novel topologies that minimize high-frequency current penetration into sensitive drivetrain components, thereby reducing losses and improving overall system performance [15]. Additionally, efforts have been made to eliminate the need for complex communication between transmitter and receiver by enabling autonomous control of the charging process through onboard systems. Simulation and experimental studies have demonstrated that such integrated approaches can achieve high efficiency while maintaining system reliability and reducing hardware requirements [1], [5]. Nevertheless, further research is required to optimize these systems for real-world applications, particularly in terms of scalability, thermal management, and compatibility with different EV architectures [8], [12].

METHODOLOGY

The proposed integrated wireless charging receiver system is developed through a systematic design and implementation procedure that combines wireless power transfer principles with existing electric vehicle drivetrain components. The methodology begins with the definition of system specifications, where a 110 kW electric vehicle drivetrain and a 6.6 kW wireless charging capacity are selected as the reference parameters. Key design constraints such as operating frequency, coil separation distance, and efficiency targets are established to ensure compatibility with practical EV charging requirements. The operating frequency is chosen in the high-frequency range to enable efficient inductive coupling, while maintaining acceptable switching losses within the power electronic devices.

In the second step, the wireless power transfer (WPT) system is designed, including both transmitter and receiver coils. A suitable coil geometry is selected to achieve strong magnetic coupling and tolerance to misalignment. Compensation networks are then incorporated on both sides to achieve resonance at the selected operating frequency, thereby maximizing power transfer efficiency. The compensation topology is carefully chosen to balance voltage and current stress across the system components. Mutual inductance and coupling coefficients are analytically calculated and validated through simulation to ensure effective energy transfer at the specified air gap distance.

The third step involves integrating the receiver-side WPT system with the EV drivetrain. Instead of employing a dedicated rectifier and DC–DC converter, the traction inverter is reconfigured to operate as an active rectifier during the charging process. This is achieved by modifying the switching strategy of the inverter switches to enable bidirectional power flow. The electric motor windings are incorporated into the circuit as passive elements, allowing the system to utilize existing hardware without introducing additional components. Special attention is given to isolating high-frequency currents from sensitive drivetrain parts by implementing appropriate filtering and control techniques.

In the fourth step, a control strategy is developed to regulate the charging process. The inverter switching is controlled using pulse-width modulation (PWM) techniques, ensuring that the rectified output meets the battery charging requirements. The system is designed such that the drivetrain inherently controls the charging current and voltage, eliminating the need for external communication with the transmitter. Feedback signals such as battery voltage, current, and state of charge are used to dynamically adjust the control parameters, ensuring safe and efficient operation under varying conditions.

The fifth step focuses on minimizing losses and enhancing system efficiency. High-frequency current paths are carefully managed to reduce conduction and switching losses within the inverter and motor windings. Soft-switching techniques and optimized switching sequences are employed to reduce switching stress and improve efficiency. Thermal considerations are also incorporated by analyzing heat generation in key components and ensuring that operating limits are not exceeded.

Finally, the entire system is modeled and simulated using MATLAB/Simulink to validate its performance. The simulation includes detailed models of the WPT system, inverter, motor, and battery. Various operating conditions, including different load levels and coil misalignments, are tested to evaluate system robustness. Key performance metrics such as charging efficiency, power transfer capability, and system stability are analyzed. The results confirm that the proposed methodology successfully integrates wireless charging with the EV drivetrain while maintaining high efficiency and reliable operation.

PROPOSED SYSTEM

The proposed system introduces an integrated wireless charging receiver architecture that utilizes the existing electric vehicle drivetrain, specifically a dual inverter drive configuration, to perform battery charging without the need for dedicated receiver-side power electronics. The system consists of a primary transmitter coil connected to a high-frequency inverter on the grid side and a secondary receiver coil mounted on the vehicle. The transmitted alternating magnetic field induces a high-frequency voltage in the receiver coil, which is then directly interfaced with the traction inverter. Unlike conventional systems that require an additional rectifier and DC–DC converter, the traction inverter is reconfigured to operate as an active rectifier, thereby converting the induced AC power into DC suitable for battery charging. The dual inverter configuration enables flexible power flow control and efficient utilization of existing switching devices, reducing system redundancy, cost, and weight. Furthermore, appropriate compensation networks are incorporated on both the transmitter and receiver sides to ensure resonance and maximize power transfer efficiency across the air gap.

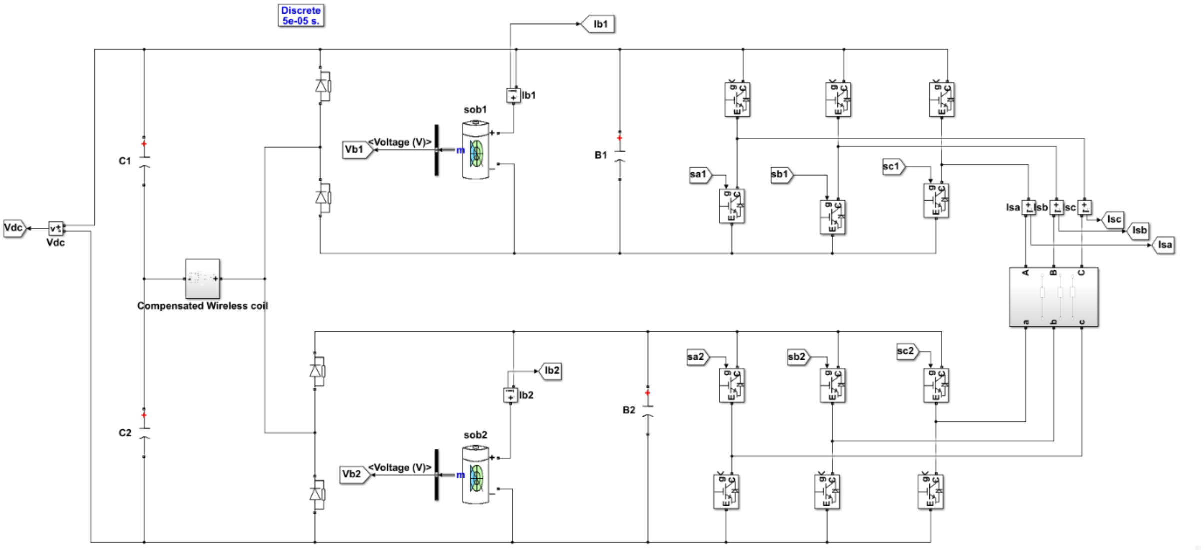


Fig 1: MATLAB/SIMULINK circuit diagram of Proposed integrated wireless charger

A key feature of the proposed system lies in its ability to manage high-frequency currents within the drivetrain while minimizing associated losses and electromagnetic interference. Since the traction inverter and motor windings are originally designed for propulsion at lower frequencies, direct exposure to high-frequency charging currents can lead to increased core losses, heating, and reduced component lifespan. To address this, the system incorporates filtering and control strategies that restrict the propagation of high-frequency components into sensitive parts of the drivetrain. The motor windings are effectively utilized as passive elements within the charging loop, but their exposure to high-frequency currents is carefully limited through circuit design and switching control. Additionally, soft-switching techniques are employed within the inverter to reduce switching losses and improve overall efficiency. This careful coordination between hardware configuration and control strategy ensures that the integrated system operates safely and efficiently without compromising the performance of the propulsion system.

Another significant advantage of the proposed configuration is the elimination of complex communication and control requirements between the transmitter and receiver. In conventional wireless charging systems, precise coordination is required to regulate power transfer, often involving additional sensors, communication links, and control algorithms. In contrast, the proposed system allows the drivetrain itself to regulate the charging process by controlling the inverter switching based on battery requirements. Parameters such as battery voltage, current, and state of charge are continuously monitored, and the inverter dynamically adjusts its operation to maintain optimal charging conditions. This decentralized control approach simplifies system design and enhances reliability by reducing dependency on external communication. Simulation results obtained using a 110 kW drivetrain and a 6.6 kW wireless charging setup demonstrate that the system achieves high efficiency and stable performance even under varying operating conditions, including changes in load and coil alignment. Overall, the proposed system provides a compact, efficient, and cost-effective solution for integrating wireless charging into modern electric vehicles.

RESULTS AND DISCUSSION

The performance of the proposed integrated wireless charging receiver system was evaluated through detailed simulation studies carried out in a MATLAB/Simulink environment. The system model included a 110 kW electric vehicle drivetrain integrated with a 6.6 kW wireless power transfer (WPT) system. Key parameters such as switching frequency, compensation network values, and coil separation distance were selected based on practical EV charging standards. The simulation was conducted under nominal operating conditions with a coil separation distance of 200 mm to reflect realistic ground clearance in electric vehicles. The results indicate that the proposed system successfully achieves stable power transfer with minimal oscillations in voltage and current waveforms. The interaction between the transmitter and receiver coils demonstrated strong magnetic coupling, enabling efficient energy transfer even without precise alignment optimization.

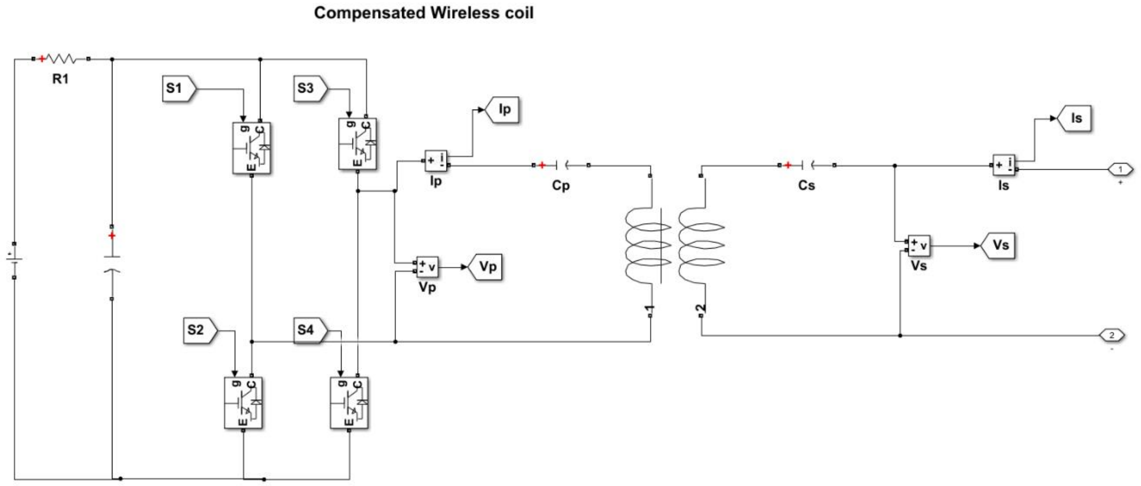
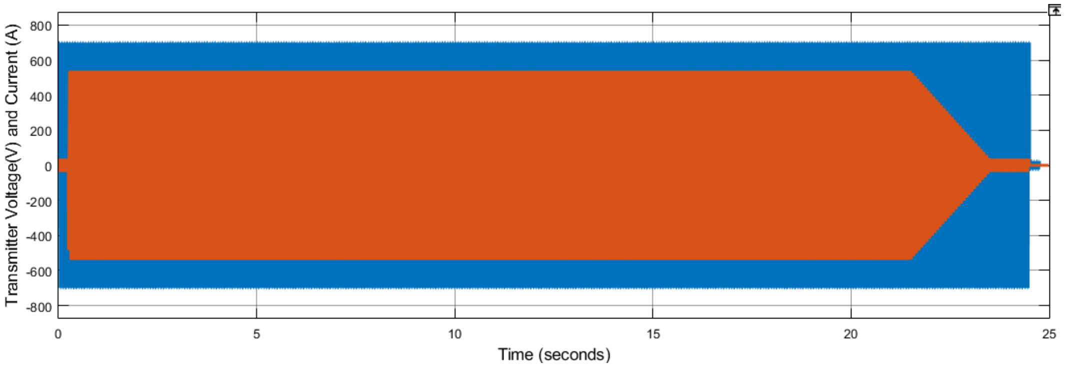
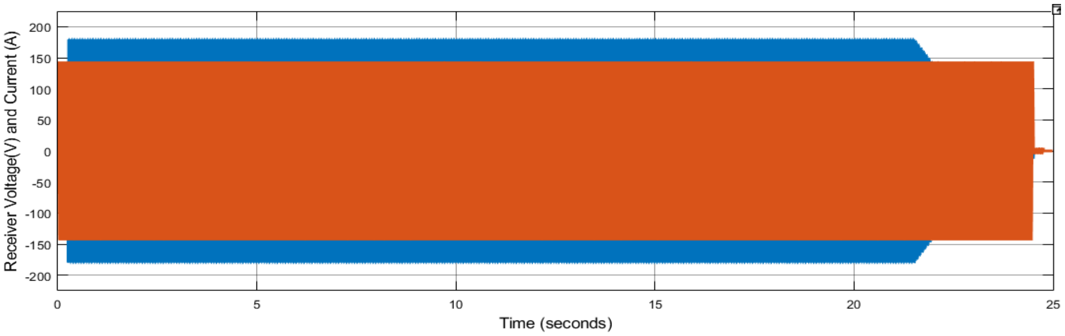


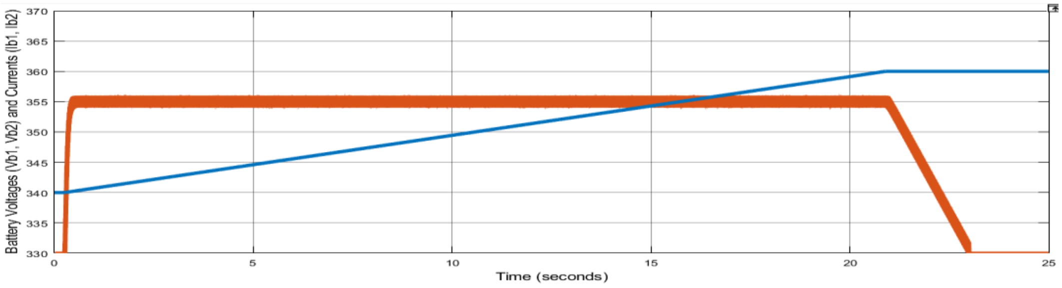
Fig 2: Subsystem of Compensated wireless coil

The charging efficiency of the system was analyzed across varying load conditions and coupling coefficients. The results show that the system achieves a peak efficiency of 94.3% at the nominal operating point, which is comparable to or better than conventional wireless charging systems that use dedicated receiver-side converters. This high efficiency is primarily attributed to the elimination of additional conversion stages and the effective utilization of the traction inverter as an active rectifier. Furthermore, the efficiency remained above 90% across a wide range of operating conditions, indicating strong robustness and adaptability. Even under partial misalignment scenarios, the system maintained acceptable efficiency levels, demonstrating its suitability for real-world applications where perfect coil alignment cannot always be guaranteed.

The voltage and current characteristics of the system were also examined to evaluate power quality and system stability. The inverter output exhibited smooth DC voltage with minimal ripple, ensuring safe and reliable battery charging. The use of appropriate compensation networks and control strategies effectively minimized reactive power circulation and reduced harmonic distortion. Additionally, the high-frequency AC currents induced in the receiver coil were successfully managed to prevent excessive stress on the inverter switches and motor windings. The waveform analysis confirmed that the system operates within safe electrical limits, thereby enhancing the reliability and longevity of the drivetrain components. A critical aspect of the proposed system is the management of high-frequency currents within the motor windings and other sensitive drivetrain components. The simulation results demonstrate that the implemented filtering and control mechanisms effectively limit the propagation of high-frequency components beyond the intended pathways. This significantly reduces core losses and thermal stress in the motor, which are common concerns in integrated charging systems. Temperature rise analysis, although conducted at a simplified level, indicated that the system remains within acceptable thermal limits under continuous charging conditions. The incorporation of soft-switching techniques further contributed to reduced switching losses and improved overall efficiency.







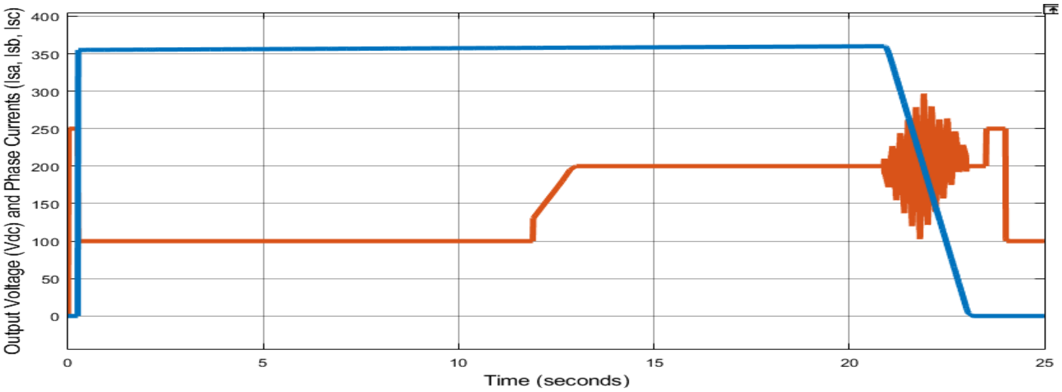


Fig 3: Simulation of complete charging cycle, where V*b_avg = 360V and the coils are well-aligned.

The dynamic response of the system was evaluated under varying battery states of charge and sudden changes in load conditions. The results show that the system responds quickly to changes, with minimal overshoot and fast settling times. The drivetrain-based control strategy effectively regulates the charging current and voltage without the need for external communication from the transmitter side. This autonomous control capability simplifies system architecture and enhances reliability. The system also demonstrated stable operation during transitions between different charging modes, highlighting its adaptability to diverse operating scenarios. Overall, the results validate the effectiveness of the proposed integrated wireless charging system in achieving high efficiency, reliable operation, and reduced system complexity. Compared to conventional approaches, the proposed method significantly reduces hardware requirements while maintaining excellent performance characteristics. The discussions highlight that the integration of the traction inverter and motor into the charging process does not adversely affect drivetrain performance when appropriate design and control strategies are implemented. The findings suggest that the proposed system is a viable and scalable solution for future electric vehicle charging infrastructure, offering both technical and economic advantages.

CONCLUSION

In conclusion, this study presented an innovative integrated wireless charging receiver architecture for electric vehicles that effectively utilizes existing drivetrain components, including the traction inverter and motor, to perform battery charging. By eliminating the need for dedicated receiver-side power electronics, the proposed system significantly reduces hardware complexity, cost, and overall system weight while maintaining high performance. The integration strategy was carefully designed to manage high-frequency currents and minimize their impact on sensitive drivetrain elements, thereby ensuring reliable and efficient operation. Simulation results demonstrated that the system achieves a high peak efficiency of 94.3% at a practical coil separation distance of 200 mm, validating its feasibility for real-world applications. Furthermore, the inherent ability of the drivetrain to regulate the charging process removes the necessity for complex communication and control mechanisms between the transmitter and receiver, enhancing system robustness. The proposed approach not only improves energy efficiency but also simplifies the overall architecture of wireless charging systems. Therefore, it represents a promising solution for next-generation electric vehicle charging infrastructure, contributing to increased adoption of wireless charging technology and supporting the advancement of sustainable transportation systems.

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