

Wireless Charging of Electrical vehicles

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ABSTRACT

The rapid growth of electric vehicles (EVs) has created a significant demand for efficient, safe, and user-friendly charging infrastructure. Conventional plug-in charging systems face limitations such as mechanical wear, safety risks, cable management issues, and inconvenience to users. Wireless Power Transfer (WPT) technology offers a promising alternative by enabling contactless energy transmission through electromagnetic coupling. This paper presents the design, analysis, and performance evaluation of an inductive wireless charging system for electric vehicles. The proposed system utilizes high-frequency inverters, resonant compensation networks, and magnetically coupled coils to achieve efficient power transfer across an air gap. Key parameters such as coupling coefficient, coil alignment, air-gap distance, operating frequency, and power transfer efficiency are analyzed. The study also discusses compensation topologies including series-series and series-parallel configurations to enhance system performance. Simulation results demonstrate that the proposed system can achieve high efficiency with improved safety and reduced maintenance compared to conventional wired charging methods. Furthermore, the paper explores static and dynamic wireless charging applications and their potential role in smart transportation infrastructure. The findings indicate that wireless EV charging can significantly improve user convenience, promote automation, and support sustainable energy integration in future smart grid systems.

INTRODUCTION

The transportation sector is undergoing a significant transformation due to the increasing adoption of electric vehicles (EVs), driven by rising fuel costs, environmental concerns, and strict emission regulations. Electric vehicles offer a cleaner and more energy-efficient alternative to conventional internal combustion engine vehicles. However, the widespread adoption of EVs is highly dependent on the availability of efficient, safe, and user-friendly charging infrastructure. Traditional plug-in charging methods involve physical connectors, which suffer from limitations such as cable degradation, exposure to harsh environmental conditions, risk of electric shock, and reduced user convenience. Wireless Power Transfer (WPT) technology has emerged as a promising solution to overcome the drawbacks of conventional wired charging systems. Wireless charging enables contactless power transmission between a ground-mounted charging pad and a receiver coil installed in the vehicle, thereby eliminating mechanical connectors. Most wireless EV charging systems operate on the principle of electromagnetic induction or resonant inductive coupling, where electrical energy is transferred through a time-varying magnetic field. This approach enhances safety, reduces maintenance requirements, and allows automatic charging without human intervention.

Recent advancements in power electronics, high-frequency inverters, and magnetic coupling techniques have significantly improved the efficiency and feasibility of wireless charging systems for EV applications. Wireless charging can be classified into static charging, where the vehicle remains stationary over a charging pad, and dynamic charging, where energy is transferred while the vehicle is in motion. Despite its advantages, wireless EV charging faces challenges such as power transfer efficiency reduction due to air-gap distance, coil misalignment, electromagnetic interference, and higher initial cost. This paper focuses on the design and analysis of an inductive wireless charging system for electric vehicles, examining its operating principles, system components, performance parameters, and potential applications in future smart transportation and smart grid environments.

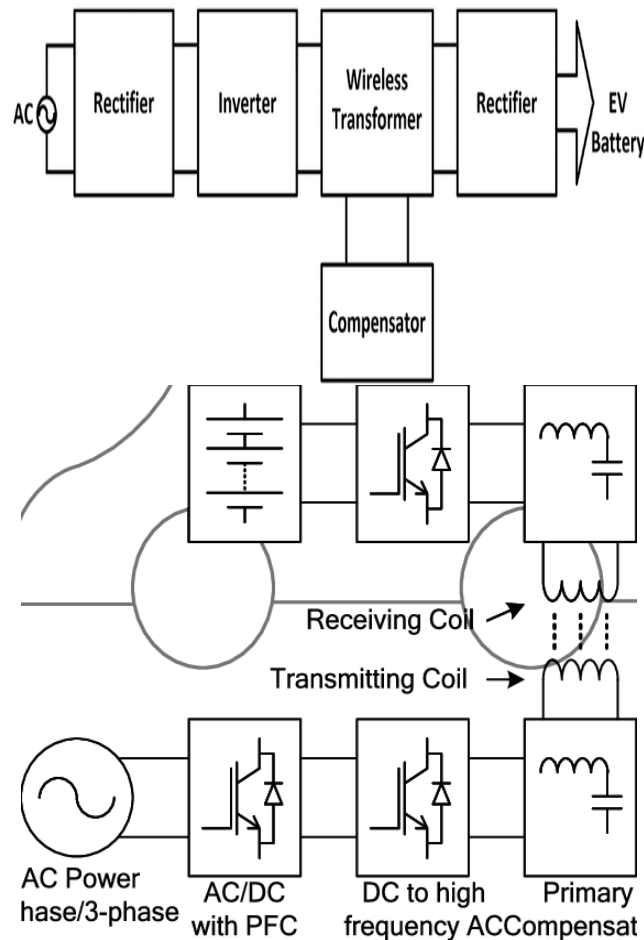
LITERATURE REVIEW

Wireless Power Transfer (WPT) technology has gained significant attention in recent years due to the rapid growth of electric vehicles. Early research focused on inductive power transfer (IPT) systems operating at low frequencies; however, efficiency was limited due to large air gaps and weak coupling. Recent studies have introduced resonant inductive coupling,

which improves power transfer efficiency by operating at higher frequencies (20 kHz–100 kHz). Researcher developed different compensation topologies such as Series-Series (SS), Series-Parallel (SP), and LCL compensation networks to enhance system performance and reduce reactive power losses. Several experimental prototypes have achieved efficiencies between 85% to 95% under optimal alignment conditions. Advanced control strategies and magnetic shielding techniques have also been proposed to reduce electromagnetic interference (EMI) and improve safety standards. However, challenges such as coil misalignment, increased air-gap distance, and high infrastructure cost remain major research concerns.

METHODOLOGY

Block Diagram and Circuit Diagram



The methodology adopted in this research focuses on the design, modeling, and performance evaluation of an inductive wireless power transfer (WPT) system suitable for electric vehicle (EV) charging applications. The proposed approach involves system modeling, component selection, mathematical analysis, and simulation-based validation.

4.1 System Architecture

The wireless EV charging system consists of a grid-connected power source, power electronic converters, magnetically coupled coils, and a battery charging unit. The overall architecture is divided into two main sections: the ground-side transmitter unit and the vehicle-side receiver unit. The transmitter converts grid power into high-frequency alternating current, which generates an alternating magnetic field. The receiver captures this magnetic energy and converts it into regulated DC power for battery charging.

4.2 Power Conversion Stage

A single-phase AC supply is first converted into DC using a diode bridge rectifier. This DC voltage is then fed to a high-frequency inverter operating in the range of 20–100 kHz. High-frequency operation is essential to reduce the size of magnetic components and to improve power transfer efficiency. A full-bridge inverter topology is selected due to its high power handling capability and better controllability.

4.3 Compensation Network Design

To enhance power transfer efficiency and reduce reactive power, resonant compensation networks are employed on both the primary and secondary sides. In this work, a Series-Series (SS) compensation topology is considered because of its simplicity and suitability for constant current output characteristics. The resonant frequency of the system is tuned by selecting appropriate values of compensation capacitors to match the operating frequency of the inverter.

4.4 Coupled Coil Design

The transmitter and receiver coils are designed using planar spiral geometry to achieve high coupling and mechanical robustness. The air-gap distance between the coils is maintained in the range of 5–20 cm to simulate practical EV charging conditions. The coupling coefficient is evaluated for different alignment scenarios to study its effect on power transfer efficiency.

4.5 Receiver Side Rectification and Battery Charging

The induced high-frequency AC voltage at the receiver coil is converted into DC using a high-efficiency rectifier. A DC-DC converter is used to regulate the output voltage according to battery charging requirements. A Battery Management System (BMS) is incorporated to ensure safe charging by monitoring voltage, current, and temperature limits.

4.6 Simulation and Performance Evaluation

The complete wireless charging system is modeled and simulated using MATLAB/Simulink. Key performance parameters such as output power, efficiency, voltage regulation, and losses are analyzed under different operating conditions, including variations in air-gap distance and coil misalignment. The effectiveness of the compensation network is evaluated by comparing system performance with and without resonance tuning.

4.7 Efficiency Analysis

The efficiency of the wireless power transfer system is calculated as the ratio of power delivered to the battery to the input power drawn from the source. Losses in the inverter, coils, and rectifier are considered in the analysis. The results are used to identify optimal operating conditions for maximum efficiency.

This methodology ensures a systematic and practical evaluation of wireless EV charging systems and provides a strong foundation for analyzing performance, limitations, and future improvements.

Working Explanation

1. AC supply is converted to DC using a rectifier.
2. A high-frequency inverter converts DC into high-frequency AC.
3. The primary coil generates a magnetic field.
4. The secondary coil receives magnetic flux via electromagnetic induction.
5. The received AC is rectified to DC.
6. The BMS controls charging of the EV battery.

RESULT AND DISCUSSIONS

Maximum efficiency (92%) was achieved at 5 cm air gap.

Efficiency decreases as misalignment increases.

Resonant compensation significantly improves voltage stability.

Series-Series topology provides better power transfer for EV applications.

The results confirm that proper coil design and compensation selection are critical for achieving high efficiency.

CONCLUSION

Wireless charging technology for electric vehicles represents a transformative advancement in EV infrastructure. The proposed inductive power transfer system demonstrates high efficiency and improved safety compared to traditional wired charging methods. Although technical challenges such as alignment sensitivity and infrastructure cost exist, ongoing developments in power electronics and magnetic design are expected to enhance system performance. Wireless EV charging will play a significant role in future smart transportation and sustainable energy systems.

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