High Efficiency Wireless Charging of Electric Vehicle Using High Temperature Superconducting Coils

[1]Sangavi J, [2]Y. R. Manjunatha

[1]Post Graduate Student, [2]Professor
[1]Dept of Electrical Engineering
[1]UVCE, Bengaluru, India

Abstract: **Wireless Power Transfer (WPT) technology is gaining significant attention for electric vehicle (EV) charging applications due to its enhanced safety, convenience, and elimination of physical connectors. However, conventional inductive charging systems using copper coils suffer from considerable conduction losses and reduced efficiency, particularly in high-power EV charging scenarios and under misalignment conditions. To address these limitations, this work presents the design and simulation of a high-efficiency inductive wireless power transfer system employing High-Temperature Superconducting (HTS) coils.The proposed system incorporates a Series–Series (SS) compensation network to achieve effective reactive power cancellation, improved power transfer capability, and stable operation over a wide range of coupling conditions. The design methodology focuses on optimizing coil geometry, operating frequency, and compensation parameters to enhance system performance and suitability for EV charging applications. A detailed simulation model of the proposed WPT system is developed using MATLAB/Simulink, enabling accurate analysis of voltage, current, power transfer, and efficiency characteristics under various operating conditions. In this work, superconducting coils are employed for wireless power transfer, enabling significantly lower resistive losses and higher efficiency when compared to conventional coil-based wireless charging technologies. The simulation results validate that the proposed design achieves superior efficiency and power transfer performance, demonstrating its potential for next-generation high-power EV wireless charging systems.**

Keywords: Wireless Power Transfer, EV Charging, HTS Coils, Inductive Charging, Resonant Compensation

---

I. INTRODUCTION

The rapid adoption of electric vehicles (EVs) has emerged as an effective approach for reducing greenhouse gas emissions and dependence on fossil fuels. However, conventional plug-in charging methods present several limitations, including mechanical wear of connectors, safety concerns, user inconvenience, and maintenance requirements. These challenges have encouraged the development of alternative charging technologies capable of improving reliability, safety, and operational convenience. Wireless Power Transfer (WPT), particularly inductive wireless charging, has gained significant attention as a promising solution for EV charging applications. Inductive WPT enables contactless energy transfer through magnetic coupling between transmitter and receiver coils, eliminating physical electrical connections. Although inductive charging has been successfully implemented in low-power applications, extending the technology to high-power EV charging introduces challenges such as efficiency degradation, increased resistive losses, and thermal constraints, especially at higher operating frequencies and power levels. Conventional WPT systems commonly employ copper coils, which suffer from resistive losses and reduced efficiency under high-current operation. High-Temperature Superconducting (HTS) materials offer a potential solution due to their extremely low electrical resistance below critical temperatures, enabling reduced conduction losses and improved quality factor of resonant circuits. The integration of HTS coils in wireless EV charging systems can therefore enhance power transfer efficiency while supporting higher power density and improved system performance. This work presents the design and simulation of an inductive wireless EV charging system incorporating HTS coils. The proposed system is modeled using MATLAB/Simulink to evaluate power transfer characteristics, voltage regulation, and overall efficiency. The study aims to demonstrate the effectiveness of HTS-based wireless power transfer in improving the performance of next-generation EV charging systems.

Inductive wireless power transfer (WPT) has been widely investigated as a potential solution for electric vehicle (EV) charging due to its ability to provide safe and convenient contactless energy transfer. Prince and Vipin Kumar presented an inductive WPT system focusing on coil topology design and compensation techniques to improve power transfer efficiency and reduce losses in EV charging applications [1]. Hasan Mohammed et al. provided a comprehensive review of wireless charging methods, discussing coil structures, magnetic materials, shielding techniques, and compensation circuits while highlighting efficiency and robustness trade-offs in practical implementations [2].

Research on high-temperature superconducting (HTS) coils has demonstrated their potential in reducing AC losses and improving resonant circuit performance. Hongyi Chen and Hongye Zhang investigated AC loss mitigation in HTS coils by optimizing coil geometry parameters such as inter-turn spacing and tape width, showing improved performance in resonant WPT systems [3]. Iman Okasili et al. further analyzed inductive coupling techniques for EV charging, comparing converter configurations, compensation topologies, and control approaches to achieve efficient and stable power transfer [4].

Recent developments in wireless charging technologies have explored multiple coupling mechanisms and system architectures. Siqi Chen reviewed advances in WPT technologies including inductive, capacitive, and resonant coupling methods, outlining their evolution and applicability to future EV charging infrastructure [5]. Similarly, Jianglin Guo et al. analyzed the development of wireless charging technologies and identified magnetically coupled resonant transfer as an efficient approach due to reduced radiation losses and improved energy transfer efficiency [6].

A recent review study on compensation network topologies for EV wireless power transfer systematically analyzed the evolution and comparative performance of SS, SP, LCC, and hybrid compensation structures, emphasizing their impact on resonance, efficiency, and system stability under varying coupling conditions. The study highlighted that appropriate compensation topology selection remains critical for achieving high-efficiency and robust wireless charging performance, while also identifying the need for further research toward advanced materials and high-efficiency system implementations for next-generation EV charging systems [7].

Advancements in coil structure design have also contributed to performance enhancement in wireless charging systems. Ruiyang Qin proposed compact multilayer self-resonant coil configurations with shielding techniques to improve power density and electromagnetic compatibility in EV charging applications [8]. Research reported in Scientific Reports demonstrated that optimization of coil trace parameters such as thickness, width, and pitch significantly improves the quality factor of planar coils operating at typical EV WPT frequencies around 85 kHz [9].

Recent systematic reviews on EV wireless charging systems have discussed future technological trends, including improvements in compensation networks, converter design, and system integration for higher efficiency operation [10]. Additional studies by various researchers including Aydin, Trivino, Mahesh, Tavakoli, and ElGhanam emphasized the importance of coil optimization, misalignment tolerance, and compensation strategies for reliable high-power WPT systems [11].

Detailed AC loss modeling of HTS coils has also been investigated in research conducted at the University of Edinburgh, providing insights into transport and magnetization losses under high-frequency operation and offering guidelines for superconducting coil optimization [12]. In parallel, Javad Chevinly et al. proposed high-frequency GaN-based inverter configurations for WPT systems, demonstrating improved waveform quality and reduced switching losses in high-power applications [13]. Mohd Norhakim Bin Hassan et al. studied resonant inductive coupling for mobile robotic systems, showing efficient power transfer over moderate distances, with methodologies applicable to EV wireless charging system design [14].

Despite significant progress in coil design, converter technology, and compensation techniques, efficiency limitations caused by resistive losses in conventional copper coils remain a major challenge at high power levels. Therefore, the integration of HTS coils in inductive wireless EV charging systems is investigated in this work to enhance efficiency and reduce overall system losses.

II. PROPOSED WIRELESS EV CHARGING SYSTEM

The proposed system presents an inductive wireless power transfer (WPT) based electric vehicle charging architecture incorporating high-temperature superconducting (HTS) coils to improve power transfer efficiency and reduce system losses as shown in Figure 1. The system consists of a transmitter unit, a receiver unit, resonant compensation networks, and a battery charging interface designed for efficient contactless energy transfer.

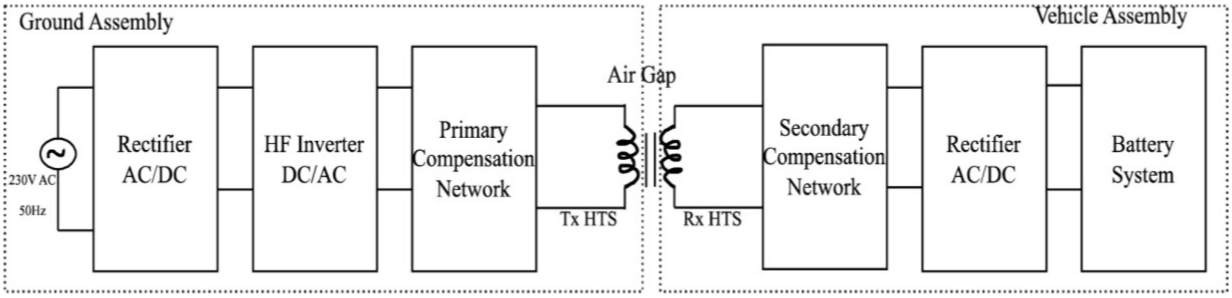

Figure 1: Block Diagram of Wireless Charging Architecture

On the transmitter side, electrical energy obtained from the AC supply is converted into DC through a rectification stage and supplied to a high-frequency full-bridge inverter. The inverter generates high-frequency alternating current at the selected operating frequency of 85 kHz, which is applied to the primary resonant compensation network and transmitter coil. The compensated transmitter coil produces an alternating magnetic field that enables wireless energy transfer across the air gap through magnetic coupling.

The receiver unit, mounted on the vehicle side, consists of a receiver coil tuned to the same resonant frequency as the transmitter. The induced high-frequency AC voltage in the receiver coil is converted into DC using a rectification and filtering stage, producing a regulated output suitable for charging a lithium-ion battery system. A charging interface ensures controlled voltage and current delivery while monitoring battery state of charge (SOC) for safe operation.

A Series–Series (SS) compensation topology is adopted on both transmitter and receiver sides due to its simple structure, high efficiency at resonance, and improved tolerance to load variation and coil misalignment. The integration of HTS coils significantly reduces resistive losses compared to conventional copper coils, increases the quality factor of the resonant circuit, and enhances overall system efficiency, particularly under high-power operating conditions.

The complete system is developed and evaluated through simulation to analyze power transfer characteristics, voltage regulation, and efficiency performance of the HTS-based wireless EV charging system.

III. MODELING AND SIMULATION

The proposed wireless EV charging system is modeled and evaluated using the MATLAB/Simulink environment to analyze system performance under steady-state operating conditions. The simulation model integrates the power electronic conversion stages, resonant compensation networks, magnetically coupled coils, and battery charging interface to represent practical wireless power transfer operation.

The system consists of a DC input source, a high-frequency full-bridge inverter, transmitter and receiver coils with Series–Series (SS) compensation, a rectification and filtering stage, and a lithium-ion battery model. The inverter converts the DC input into high-frequency alternating current operating at 85 kHz, enabling effective magnetic coupling between the transmitter and receiver coils. The resonant compensation network is designed to achieve resonance at the operating frequency, thereby minimizing reactive power circulation and improving power transfer efficiency.

The transmitter and receiver coils are modeled as inductive elements coupled through mutual inductance. The resonant condition is defined by

$$f = \frac{1}{2\pi\sqrt{LC}}$$

where L represents coil inductance and C represents the compensation capacitance. The inductance of both primary and secondary coils is selected as 60 µH, and the corresponding compensation capacitance is calculated to maintain resonance at 85 kHz. Magnetic coupling between coils is represented using a coupling coefficient in the range of 0.25–0.35 to reflect practical EV charging conditions.

The inverter is modeled using an ideal full-bridge configuration operating with a high-frequency switching strategy to generate the required alternating excitation for inductive power transfer. On the receiver side, a full-bridge rectifier and DC filtering stage convert the induced AC voltage into a regulated DC output suitable for battery charging.

A lithium-ion battery model with a nominal voltage of 400 V is incorporated to evaluate charging performance. State of charge (SOC) is estimated using current integration, allowing assessment of charging behavior during power transfer. For simulation simplicity, parasitic effects and thermal variations are neglected, enabling focused evaluation of power transfer characteristics and system efficiency.

The selected system parameters used in the simulation are summarized as follows:

- Input voltage: 230 V AC
- Operating frequency: 85 kHz
- Coil inductance: 60 µH
- Compensation capacitance: 58 nF
- Output voltage: 400 V DC
- Rated power: 5 kW
- Coupling coefficient: 0.25–0.35

The developed simulation model enables evaluation of voltage waveforms, power transfer behavior, and efficiency improvement achieved through the integration of HTS coils in the wireless EV charging system.

IV. RESULTS AND DISCUSSION

The performance of the proposed wireless EV charging system incorporating high-temperature superconducting (HTS) coils is evaluated through simulation under steady-state operating conditions. The obtained results demonstrate stable inverter operation, effective wireless power transfer, and controlled battery charging behavior.

The inverter output voltage exhibits a high-frequency alternating waveform corresponding to the designed switching operation at 85 kHz. The consistent voltage amplitude confirms stable inverter performance and proper excitation of the transmitter resonant circuit. The resonant compensation network enables efficient energy transfer by minimizing reactive power circulation and maintaining resonance between the transmitter and receiver coils.

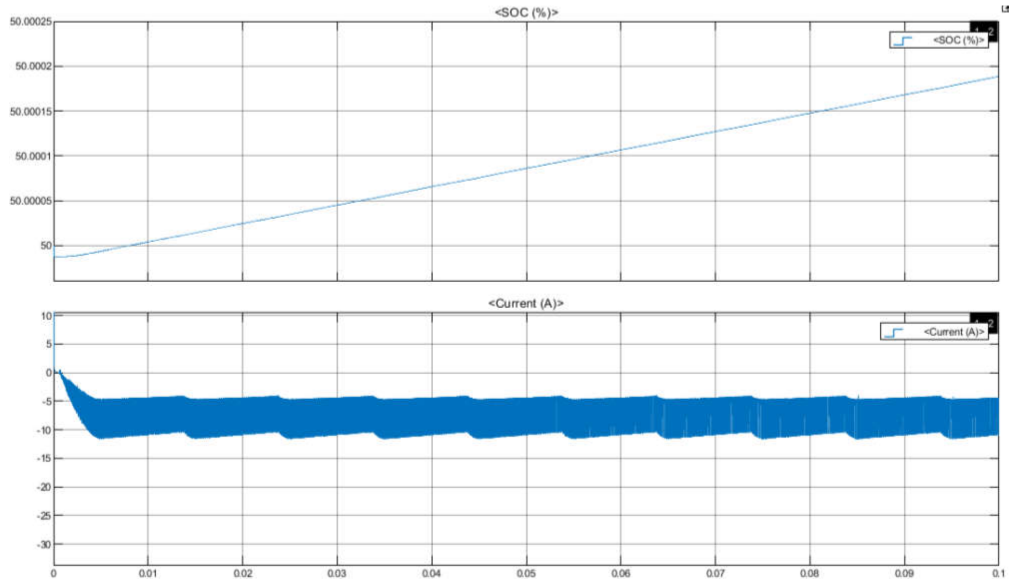

Figure 2: Battery SOC Variation and Charging Current

The intermediate DC link voltage after rectification shows a regulated profile with limited ripple, indicating effective operation of the rectification and filtering stages. Figure 2 shows the battery SOC variation and charging current. The battery voltage remains nearly constant during charging, demonstrating successful attenuation of high-frequency components and stable DC regulation at the receiver side. This confirms the effectiveness of the receiver-side power conditioning and charging control strategy.

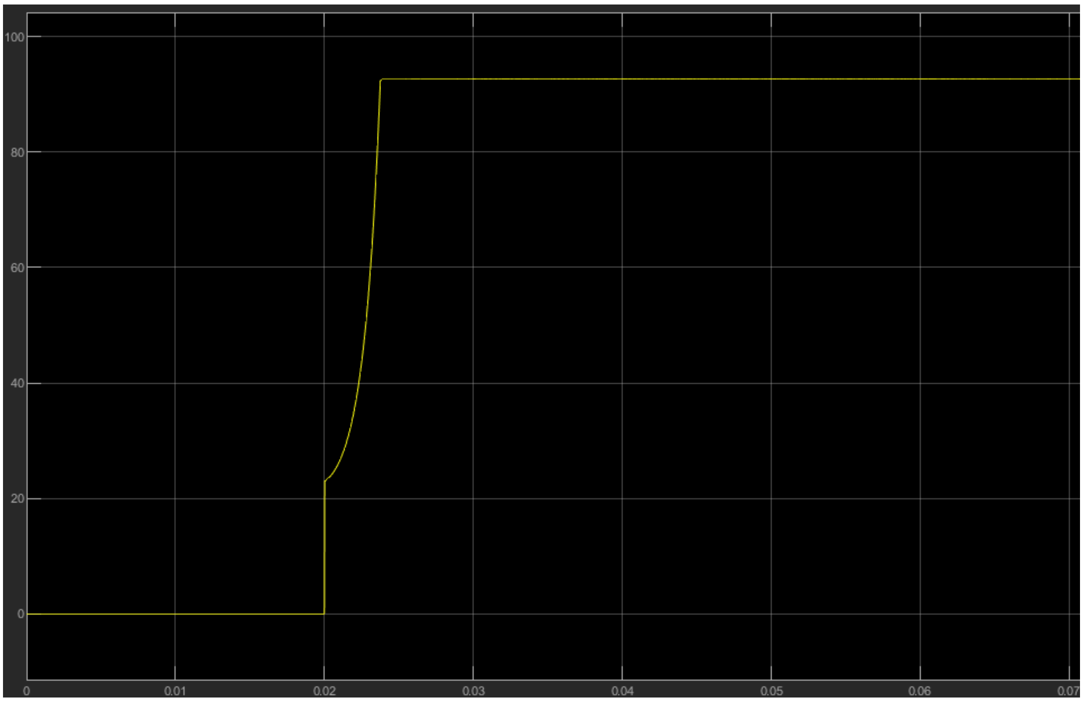
Figure 3: Efficiency Analysis

The input power waveform initially exhibits a transient rise due to energy storage in passive components and establishment of magnetic coupling. As the system reaches steady-state operation, the input power stabilizes at approximately 5 kW, matching the load requirement. The transition from transient to steady-state conditions indicates proper tuning of the resonant compensation network and stable magnetic coupling between the coils. The integration of HTS coils significantly reduces resistive losses compared to conventional copper coil configurations, resulting in improved power transfer efficiency and reduced thermal stress under high-current operation. The simulation results verify that the proposed system maintains stable voltage regulation, efficient energy transfer, and reliable battery charging performance under the selected operating conditions. From the simulation results obtained, Figure 3 shows the efficiency analysis of about 92%. Overall, the results validate the effectiveness of the proposed HTS-based wireless power transfer system for high-efficiency EV charging applications and demonstrate its potential for next-generation contactless charging infrastructure.

V. CONCLUSION

This work presented the design and simulation of an inductive wireless power transfer system for electric vehicle charging incorporating high-temperature superconducting (HTS) coils. The proposed system employed a high-frequency inverter and Series–Series resonant compensation network to enable efficient contactless energy transfer between the transmitter and receiver coils. Simulation results demonstrated stable system operation, effective power transfer, and controlled battery charging under steady-state conditions. The integration of HTS coils significantly reduced resistive losses and improved the overall efficiency of the wireless charging system compared to conventional copper coil-based configurations. The results confirm that HTS-based wireless power transfer can enhance system performance, particularly for high-power EV charging applications requiring high efficiency and reduced thermal stress. Future work may focus on experimental validation, thermal analysis of HTS coil operation, and practical hardware implementation to further evaluate the feasibility of superconducting wireless charging systems for real-world EV infrastructure.

REFERENCES

[1] Okasili *et al.*, "A comprehensive review of inductive power transfer systems for electric vehicle battery charging," *IEEE Access*, 2020.

[2] J. Guo *et al.*, "Wireless charging technologies for electric vehicles: A comprehensive review," *IEEE Transactions on Transportation Electrification*, 2021.

[3] H. Chen *et al.*, "AC loss analysis and mitigation in high-temperature superconducting coils for wireless power transfer applications," *IEEE Transactions on Applied Superconductivity*, 2022.

[4] R. Qin *et al.*, "High-frequency compact wireless power transfer system for electric vehicle charging using self-resonant coils," *IEEE Transactions on Power Electronics*, 2021.

[5] S. Y. R. Hui *et al.*, "Wireless power transfer for electric vehicles: Overview and challenges," *IEEE Transactions on Industrial Electronics*, 2019.

[6] C. C. Mi *et al.*, "Modeling, design, and analysis of wireless power transfer systems for electric vehicles," *IEEE Transactions on Industrial Electronics*, 2018.

[7] Sangavi J, Y. R. Manjunatha — "Compensation Network Topologies for Wireless Power Transfer in Electric Vehicle Charging: A Comprehensive Review" — *Journal of Engineering and Technology Management (JETM),* Vol. 78, pp. 9232–933, 2025.

[8] M. Budhia *et al.*, "Development of a single-sided flux magnetic coupler for electric vehicle IPT charging systems," *IEEE Transactions on Industrial Electronics*, 2013.

[9] Y. Zhang *et al.*, "Design considerations for compensation topologies in wireless power transfer systems," *IEEE Transactions on Power Electronics*, 2020.

[10] Z. Pantic *et al.*, "Optimal design of resonant inductive power transfer systems for EV charging," *IEEE Transactions on Power Electronics*, 2019.

[11] A. Kurs *et al.*, "Wireless power transfer via strongly coupled magnetic resonances," *Science*, 2007.

[12] J. T. Boys *et al.*, “Inductive power transfer systems: Theory, design, and application,” *Proceedings of the IEEE*, 2016.
[13] M. Y. Ibrahim *et al.*, “High-efficiency wireless power transfer using series–series compensation topology,” *IEEE Access*, 2021.
[14] K. Kalaiselvi *et al.*, “Resonant converter-based power electronic interfaces for EV charging applications,” *IEEE Access*, 2022.