Wireless Electric Vehicle Charging Using Resonant Converters: A Comprehensive Study

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***Abstract*—Wireless Power Transfer (WPT) is emerging as a key technology for improving the convenience, safety, and automation of Electric Vehicle (EV) charging. Resonant converters form the core of modern inductive WPT systems due to their capability to achieve soft switching, high efficiency, and tolerance to misalignment. This paper presents a comprehensive study of wireless EV charging using resonant converters, covering operating principles, compensation topologies, control strategies, electromagnetic considerations, system modeling, and emerging standards such as SAE J2954. Simulation methodology, design recommendations, and future research directions are also included to support academic investigation and prototype development.**

***Index Terms*—Electric vehicle charging, inductive coupling, LCC, misalignment tolerance, resonant converters, wireless power transfer.**

I. INTRODUCTION

Wireless charging for electric vehicles (EVs) uses electromagnetic coupling to transfer energy between a ground-side primary and a vehicle-side secondary coil without direct electrical contacts. Resonant wireless power transfer (WPT) is attractive for EVs because resonant coupling can extend power-transfer distance and improve efficiency relative to strongly coupled short-range inductive schemes. Resonant converters (series, parallel, and hybrid LCC topologies) form the heart of modern WPT transmitters and receivers, implementing power conversion, frequency tuning, and impedance matching. This paper surveys the state of the art in resonant converter design for EV WPT, maps key design choices to performance outcomes, and outlines practical implementation and testing guidance.

II. BACKGROUND AND LITERATURE REVIEW

WPT systems for EVs generally consist of an inverter and resonant transmitter on the grid side, a magnetically coupled coil pair, and a rectifier and resonant receiver on the vehicle side, followed by power electronics interfacing with the battery management system. Resonant systems rely on tuned LC networks to form high-Q resonators that concentrate energy at the operating frequency, improving transfer efficiency across larger air gaps and under coil misalignment.
Prior work has examined converter topologies such as series–series, series–parallel, parallel–parallel, and LCC/LCL hybrids, as well as coil designs including pancake and double-D structures. Control methods such as frequency tracking, phase shift modulation, and impedance tuning have also been reported. Key challenges include minimizing switching and conduction losses, ensuring electromagnetic compatibility, and achieving robustness to misalignment.

III. RESONANT CONVERTER TOPOLOGIES FOR EV WPT

A. Series–Series (S–S) Topology

In the S–S topology, both transmitter and receiver resonate in series with their respective coils. This approach offers simplicity and low component count but is sensitive to load and coupling variations.

B. Series–Parallel (S–P) and Parallel–Series (P–S)

Mixed series and parallel compensation improve voltage regulation and reduces sensitivity to coupling coefficient changes. The S–P topology is widely used to enhance output stability.

C. LCC Topology

LCC compensation networks are popular for EV WPT systems due to their load-independent behavior near resonance and their ability to achieve soft switching, thereby reducing switching losses and improving efficiency.

D. Hybrid and Adaptive Matching Topologies

Advanced systems employ adaptive matching networks to dynamically tune impedance, enabling reliable operation under varying load and alignment conditions.

IV. MODELING AND DESIGN CONSIDERATIONS

A. Coupled-Coil Model

The coupled-coil model represents the system using two resonant circuits coupled by mutual inductance. The coupling coefficient and quality factors significantly influence power transfer efficiency.

B. Operating Frequency Selection

Operating frequencies typically range from tens to hundreds of kilohertz. While higher frequencies reduce component size, they increase switching losses and electromagnetic interference.

C. Coil Design and Misalignment

Coil geometry strongly affects coupling and misalignment tolerance. Double-D coils and ferrite shielding are commonly used to improve efficiency and reduce stray fields.

D. Loss Mechanisms

Losses arise from switching devices, passive components, copper and core losses in coils, eddy currents in nearby metallic structures, and rectification stages.

V. CONTROL, SAFETY, AND STANDARDS

Frequency and impedance control techniques are employed to maintain resonance and regulate power transfer. Soft-switching methods such as ZVS and ZCS are widely used. Safety considerations include electromagnetic field exposure limits, foreign object detection, and thermal management. Industry standards guide frequency bands, safety limits, and interoperability requirements.

VI. SIMULATION AND EXPERIMENTAL GUIDELINES

A representative mid-power EV wireless charging system can be designed using an LCC-compensated primary, series-compensated secondary, and frequency-tracking control. Simulation tools such as MATLAB/Simulink and PLECS are commonly used to validate system performance before hardware implementation.

VII. CONCLUSION

Resonant converter-based wireless charging systems offer a practical and efficient solution for electric vehicle charging. Proper selection of compensation topology, control strategy, and coil design enables high efficiency and misalignment tolerance. Future research should focus on adaptive matching, dynamic charging, and improved standardization.

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