Abstract

Index Terms: Bidirectional Inductive Wireless power transfer, electric vehicle charging, Coil design, finit element method, ground assembly, vehicle assembly, misalignment, compensation networks, electrical resonance, Dual phase-shift control, Optimal efficiency, Dynamic modeling, Multi variable control, wireless communication, zero phase angle, full zero voltage switching.

This thesis presents the design, modeling, and optimization of a bidirectional inductive wireless power transfer (BWPT) system for electric vehicle (EV) charging, focusing on improving efficiency and ensuring robust control under varying conditions such as misalignment and load variations.

The shift toward EVs is a cornerstone of global efforts to reduce carbon emissions and foster sustainable development. Wireless charging has emerged as a preferred solution within this transformative landscape, offering a seamless and efficient alternative to conventional plug-in systems. Wireless charging enhances user convenience and reliability by eliminating cumbersome cables and connectors, addressing the challenges posed by incompatible charging standards. Beyond convenience, wireless power transfer (WPT) introduces a versatile "park-and-charge" capability, simplifying EV charging in residential, workplace, and commercial environments.

Moreover, the bidirectional functionality of WPT systems supports both Grid-to-Vehicle (G2V) and Vehicle-to-Grid (V2G) power flow, enabling EVs to serve as mobile energy assets. These systems can feed surplus power back to the grid during peak demand, reducing reliance on extensive energy storage infrastructure and providing reactive power support. This integration of functionality not only improves energy utilization but also enhances grid stability. Consequently, BWPT systems are poised to revolutionize EV accessibility and energy management, paving the way for a more sustainable, resilient, and efficient energy ecosystem. Developing such systems requires a multidisciplinary approach encompassing power electronics, magnetic circuit design, and control strategies, with this thesis focusing on key advancements in magnetic design and robust control.

The first objective of this research is to optimize the IWPT coil design for im-

proved energy transfer efficiency while minimizing copper usage. Circular coils are explored due to their ease of alignment and adaptability. A Type-1 IWPT system coil is optimized using 3D finite element method (FEM) analysis, considering parameters like vertical offset and coil misalignment to maximize coupling efficiency. Additional optimization reduces coil weight, copper usage, and losses, ensuring compliance with SAEJ2954 standards and ICNIRP guidelines.

The second objective is to develop an accurate and dynamic model for the BWPT system using Generalized State Space Averaging (GSSA) and Extended Describing Function (EDF) methods. This model integrates multiple control variables and accounts for their interdependencies, which is essential for advanced strategies like the dual-phase shift (DPS) method. A novel input reactive power control strategy for S-S compensated BWPT systems is also introduced, improving efficiency by managing reactive power without compromising stability. However, analysis and experimental results reveal that DPS control with multiple output variables introduces a cross-coupling effect, degrading the system's dynamic performance. A relative gain array (RGA) analysis is performed to find the degree of cross-coupling due to the interdependencies formed by the multiple control and output variables.

To address this issue, a unified control approach is proposed, utilizing a single vehicle assembly (VA) side PI controller. This minimizes cross-coupling and ensures stable bidirectional power flow by controlling the VA side phase shift for constant output power and the ground assembly (GA) side phase shift for a zero power factor angle (ZPA). This approach achieves high efficiency even under misalignment. Additionally, due to its symmetry on both sides, this method provides simple bidirectional power flow control of the BWPT system. The final objective aims to improve system efficiency under varying load and misalignment conditions by evaluating performance under ZPA and full zero voltage switching (FZVS) modes. This research identifies the conditions necessary to achieve FZVS and ZPA operation, establishing optimal operating parameters to maximize efficiency. A comprehensive mathematical analysis of the trade-offs between ZPA and FZVS is conducted, utilizing a detailed loss model of the system across different operating scenarios to provide valuable insights into their influence on overall system performance.

Overall, this thesis contributes a comprehensive framework for designing and controlling BWPT systems, achieving high efficiency, stability, and performance under challenging conditions, thereby advancing wireless EV charging technology and paving the way for future innovations.

Teams Link

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