

Design and Simulation of a Bidirectional Inductive Power Transfer System for EV Grid Integration

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ABSTRACT

In this paper, a grid-connected bidirectional wireless charging system for electric vehicle (EV) applications is designed and implemented using MATLAB/Simulink. The proposed system is based on inductive power transfer (IPT) with a high-frequency resonant converter and an LCL-compensated pad structure to achieve efficient and contactless power transfer between the grid and the EV battery. The bidirectional operation enables both grid-to-vehicle (G2V) charging and vehicle-to-grid (V2G) power injection, thus supporting ancillary services and improving the flexibility of modern power systems. A detailed system model including grid interface, DC-link control, resonant converter, and battery charging profile is developed. The control strategy is designed to regulate the DC-link voltage, ensure zero-voltage switching (ZVS) of power electronic switches, and maintain constant current/constant voltage (CC/CV) charging of the battery. Simulation studies are carried out in MATLAB/Simulink under different loading and coupling conditions. The results demonstrate that the proposed system achieves high efficiency, acceptable voltage and current waveforms, and stable bidirectional power flow with low total harmonic distortion (THD). The proposed topology can be effectively used for future smart charging infrastructures and integration of EVs into modern power systems.

Keywords: - Electric vehicle; Wireless power transfer; Inductive power transfer; Bidirectional converter; Vehicle-to-grid; MATLAB/Simulink.

I. INTRODUCTION

The increasing global concern over depletion of fossil fuel reserves and their adverse effects on the environment have resulted in fast development in technologies like renewable energy generation and EVs. Conductive charging has been long introduced but is still not preferred due to tripping hazards, leakage from old cracked cables (particularly in cold zones), risk of electric shock etc. Major drawback of present EVs is the power storage technology, usually battery, which has very unsatisfactory performance. Long charging time of EV batteries is the main reason for its low popularity among consumers. Introduction of wireless power transfer for EV battery charging is thus being considered as a probable solution for aforementioned issues in conductive charging. Wireless charging technique provides several advantages like galvanic isolation, convenient and safe usage in addition to low maintenance due to no physical contacts or moving parts. Also, the battery capacity of EVs with

wireless charging could be reduced to 20% or less compared to EVs with conductive charging. Most of the developments in WPT technology have mainly been in applications requiring unidirectional power transfer. In recent years, BD-WPT systems have become popular for implementing the concept of Vehicle to Grid (V2G) for grid integration of EVs. To reduce the effects caused due to intermittent nature of renewable energy systems and facilitate dynamic demand management, V2G concept can be used as cost-effective alternate energy storage unit. In this work, a complete system depicting V2G and G2V concept for controlling desired power transfer between grid and EV battery, along-with ensuring unity power factor at grid side has been analyzed and simulated in MATLAB.

II. LITERATURE REVIEW

Wireless power transfer (WPT) based on inductive coupling has emerged as a promising solution for electric vehicle (EV) charging due to its safety, convenience, and elimination of physical connectors. In recent years, research attention has expanded from unidirectional charging to bidirectional inductive power transfer (IPT)

systems, enabling grid-to-vehicle (G2V) and vehicle-to-grid (V2G) operation for enhanced grid support and energy management.

Early studies on inductive EV charging primarily focused on unidirectional power flow, addressing challenges such as magnetic coupling design, compensation topologies, and efficiency improvement. However, with the increasing penetration of EVs and renewable energy sources, bidirectional power flow has become essential for grid stabilization and ancillary services. Xia et al. [1] proposed a bidirectional wireless power transfer system incorporating a relay circuit to improve transmission distance and efficiency, demonstrating the feasibility of bidirectional energy exchange.

Control strategies play a critical role in ensuring stable bidirectional operation. Buja et al. [2] presented a comprehensive control scheme for a bidirectional IPT system integrated into the grid, enabling seamless transition between G2V and V2G modes. Their work emphasized phase-shift control and resonant compensation to regulate power flow while maintaining high efficiency. Similarly, Arulvendhan et al. [3] designed a bidirectional wireless charging system using a DC–DC converter to support both charging and discharging modes in V2G applications.

Several studies have focused on optimizing resonant compensation networks and soft-switching conditions to enhance system efficiency. Zhang et al. [5] analyzed a constant-current/constant-voltage (CC/CV) bidirectional IPT system and achieved a wide zero-voltage-switching (ZVS) range, which is essential for reducing switching losses during bidirectional operation. Chen et al. [6] further extended this concept by developing interoperable high-efficiency bidirectional WPT systems capable of charging multiple EVs.

Comprehensive review articles have summarized recent advancements in bidirectional wireless charging technologies. Khaligh and Dusmez [7] reviewed converter topologies, magnetic coupling structures, and control techniques used in bidirectional IPT systems for EV-grid integration. Kumar and Jain [8] provided an in-depth analysis of power electronic converters and control schemes for V2G wireless charging applications. Additionally, Chopra et al. [9] and Lu et al. [10] reviewed compensation methods, misalignment tolerance, and standardization efforts in IPT-based EV charging systems.

Grid integration aspects have also been explored extensively. Xiong et al. [11] proposed real-time bidirectional EV charging control strategies for grid support, while Schmutzler et al. [12] validated bidirectional EV chargers through field testing in residential grid environments. Although these studies focus mainly on conductive charging, their control concepts are applicable to inductive systems. Moreover, optimized magnetic coupling design for V2G wireless charging stations has been investigated to improve power density and efficiency [13].

Despite significant progress, challenges remain in achieving high efficiency under misalignment, ensuring stable bidirectional power control, and complying with emerging standards such as SAE J2954 and ISO 15118 [14], [15]. Therefore, this paper focuses on the design and simulation of a bidirectional **IPT system**, emphasizing resonant topology selection, control strategy, and grid-interactive operation for EV applications.

III. BIDIRECTIONAL WPT SYSTEM ARCHITECTURES

A typical BWPT system consists of a grid-side power converter, a high-frequency resonant compensation network, magnetically coupled transmitter and receiver coils, and a vehicle-side bidirectional DC interface. Early implementations employed relay-assisted circuits to reverse power flow [1]. More recent architectures utilize fully controllable bidirectional converters, enabling seamless transition between G2V and V2G modes [2], [4].

Advanced system designs focus on modularity and interoperability to support public and residential charging infrastructure. Interoperable high-efficiency BWPT architectures have been reported to improve scalability and compliance with emerging standards [6], [13].

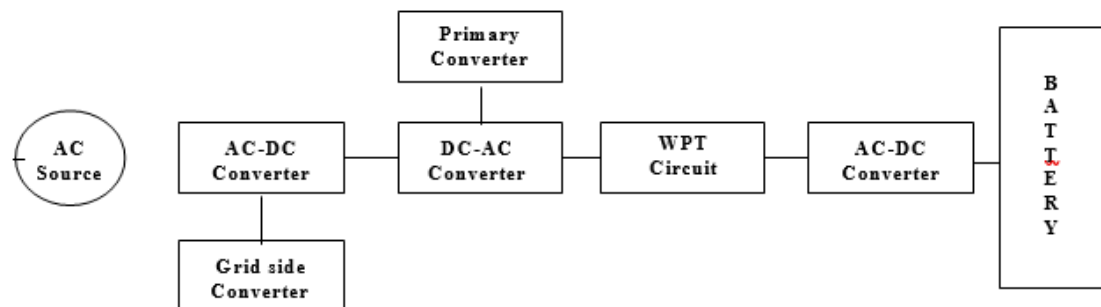


Figure 1. Block diagram of the proposed bidirectional IPT system.

IV. POWER CONVERTER TOPOLOGIES AND CONTROL METHODS

Bidirectional power flow in WPT systems is commonly achieved using full-bridge inverters and dual-active bridge (DAB) converters. These topologies provide symmetrical operation and high efficiency under varying load conditions. Resonant compensation networks such as series-series and LCC topologies are widely employed to reduce reactive power and switching losses.

Control strategies including phase-shift modulation, frequency control, and constant-current/constant-voltage (CC/CV) charging are used to regulate power transfer and battery charging profiles [5]. Grid-interactive and real-time control approaches have been demonstrated to ensure stable V2G operation while meeting grid requirements [11]. Recent studies emphasize coordinated control strategies to enable smooth mode transitions and high efficiency [6], [8].

V. MAGNETIC COUPLING DESIGN AND STANDARDS

The performance of BWPT systems is strongly influenced by magnetic coupling characteristics. Coil geometry optimization, ferrite shielding, and compensation network design are employed to improve coupling coefficients and misalignment tolerance. Optimized magnetic coupling stages for EV-to-grid charging stations have been reported to enhance efficiency and power density [13].

Standardization plays a critical role in ensuring safety and interoperability. The SAE J2954 standard specifies power classes, alignment tolerances, and efficiency requirements for wireless EV charging systems [14]. In addition, ISO 15118 defines the communication interface for secure V2G operation, enabling authentication, billing, and energy management [15].

VI. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Despite significant progress, several challenges remain in the deployment of BWPT systems. These include efficiency degradation under coil misalignment, electromagnetic interference, high system cost, and compliance with grid codes. Future research efforts are expected to focus on the use of wide-bandgap semiconductors, intelligent control algorithms, dynamic wireless charging, and large-scale V2G coordination [7], [9], [10].

MATLAB/Simulink Model

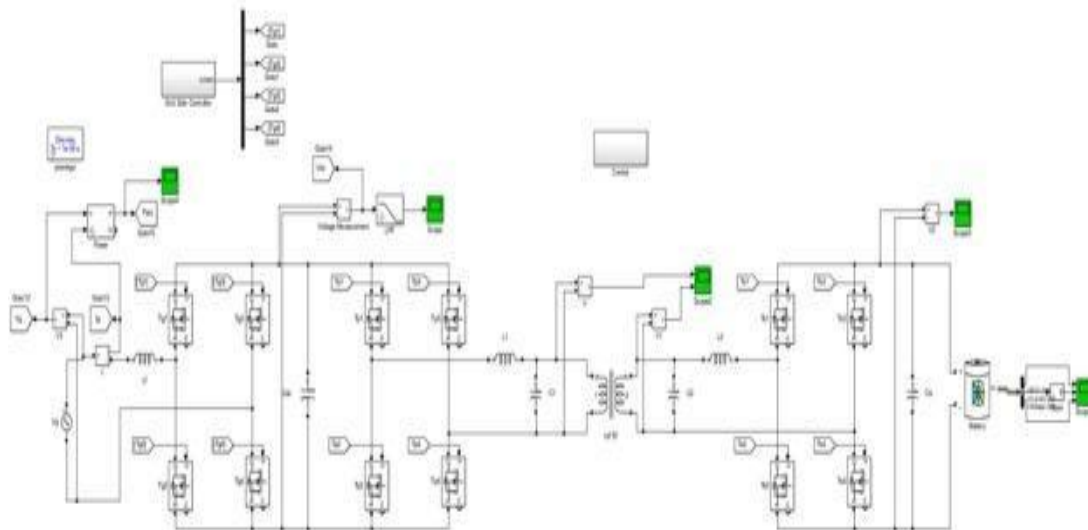


Fig 2 The proposed MATLAB SIMULINK test of BD-IPT system

VII. CONCLUSIONS

This work presents the modeling and simulation of a grid-connected bidirectional wireless charging system for electric vehicle applications using MATLAB/Simulink. The system operates on inductive power transfer principles and employs a high-frequency resonant converter with LCL compensation to achieve efficient and contactless energy transfer between the utility grid and the EV battery. Bidirectional functionality enables both charging and discharging modes, allowing power flow from the grid to the vehicle as well as from the vehicle back to the grid. The developed simulation model integrates the grid-side interface, DC-link regulation, resonant power conversion, and battery charging control. Simulation results indicate stable system behavior with satisfactory voltage and current characteristics, demonstrating the practicality of the proposed bidirectional wireless charging approach for future EV charging infrastructure and smart grid applications.

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