# "Innovative Approaches to Wireless Power Transfer System Design for Electric Vehicles"

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**Abstract:**

Wireless Power Transfer (WPT) systems provide efficient and convenient EV charging. This study investigates novel approaches to the design, modeling, and assessment of WPT systems, focusing on their potential to transform EV charging infrastructure. The study focuses on important features of WPT technology, such as inductive and resonant coupling, power transfer efficiency, and system reliability. Advanced modeling approaches are used to simulate and study the performance of different WPT configurations under real-world operating situations. Comparative studies are carried out to assess system designs using factors like as transfer distance, alignment sensitivity, thermal performance, and electromagnetic compatibility. New materials and coil designs are also evaluated for their effect on efficiency and cost-effectiveness. The findings demonstrate the advantages of improved WPT designs in terms of minimizing charging time, increasing user convenience, and promoting EV adoption. This study provides a complete framework for building next-generation WPT systems that meet technological obstacles while being consistent with current transportation's sustainability aims. This work optimizes and controls the series-series (SS) WPT compensation topology for grid-to-vehicle (G2V) mode using MATLAB/Simulink.A simulation analysis is undertaken for a chosen WPT design for G2V mode to assure its operation and performance in various power levels.

**Keywords:** grid-to-vehicle (G2V), electric vehicles, compensatory topologies, wireless power transfer (WPT), design and control techniques

## Introduction

The global shift toward sustainable transportation has placed electric vehicles (EVs) at the forefront of efforts to reduce carbon emissions and dependence on fossil fuels. As the adoption of EVs accelerates, the demand for efficient, convenient, and user-friendly charging solutions has intensified. Traditional plug-in charging systems, while effective, face limitations in terms of practicality, user experience, and infrastructure scalability. Wireless Power Transfer (WPT) systems offer a promising alternative by enabling contactless energy transfer, enhancing convenience, and reducing wear on physical connectors. WPT technology operates on the principles of electromagnetic induction and resonant coupling, allowing power to be transmitted through an air gap between a charging pad and a receiver coil embedded in the vehicle. The inherent advantages of WPT systems, such as safety, ease of use, and potential for dynamic charging, have positioned them as a key enabler of future smart mobility solutions. However, significant challenges remain in optimizing power transfer efficiency, minimizing energy losses, addressing electromagnetic interference, and ensuring compatibility with diverse EV designs.

This paper presents innovative approaches to the design and analysis of WPT systems tailored for EV applications. It focuses on advanced methodologies for system modeling, performance optimization, and comparative evaluation of various design configurations. By integrating emerging materials, novel coil geometries, and cutting-edge control techniques, the study aims to push the boundaries of WPT efficiency and scalability. The findings provide insights into overcoming technical barriers and paving the way for the widespread adoption of wireless charging technologies in the EV sector.

Electric vehicles (EVs) are a viable option for lowering greenhouse gas emissions compared to traditional vehicles powered by internal combustion engines. In recent years, the commercialization of electric vehicles has considerably increased because to Recent advancements in battery technology, power electronics interfaces (inverters, DC/DC converters, on/off-board charging systems), electric motors, and power management control [1].

The number of EVs in circulation is increasing year after year. The European Automobile Manufacturers' Association (ACEA) reported that over 190,000 plug-in electric and hybrid vehicles were sold in Europe in the first nine months of 2015, representing a significant increase. Approximately 95% in contrast to 2014 [2]. EVs face significant challenges, including high battery costs, short battery life, sluggish charging, inefficient charging methods, low energy density, weight, and dependability. Inadequate infrastructure, including charging stations, is a major barrier to EV growth [3].

Charging stations are ideal for areas where vehicles are parked for extended periods, such as garages, restaurants, hotels, cottages, public parking areas, camping sites, shopping centers, business parks, and sports centers [4,5]. Optimizing EV drivetrains and management systems for maximum energy efficiency and low total cost of ownership (TCO) is a key challenge. According to a 2010 Ernst & Young survey (cited in [6]), access to charging stations is a major barrier to popular adoption of electric vehicles. The inconvenience and safety concerns connected with charging are a major barrier to wide market adoption of electric vehicles.

Many studies focus on fast-charging systems and safety concerns for light-duty electric vehicles (EVs). Plug-in charging remains the preferred way for charging electric cars (PHEVs and EVs), as conductive charging is the standard power transmission method. Conductive charging systems rely on metal-to-metal contact, as seen in most appliances and electrical equipment. Environmental factors such as rain, ice, snow, and severe temperatures can provide complications for plugs and wires. Another downside of this conductive technology is the manual connection between EVs and charging stations. Charging electric vehicles at public charging stations might be inconvenient for users.

Wireless power transfer (WPT) technology now allows for remote charging of electric vehicles [7-9]. Meanwhile, WPT technology is used in fast-charging systems currently on the market, such as City battery buses [10]. This is one of the most reliable uses for alternative charging. Several projects have used inductive charging for buses, including Scania (Sweden, 2016), Flanders DRIVE (Belgium, 2011), City of Den Bosch (the Netherlands, 2012), Bombardier (Germany, 2013), Dong Won Olev (South Korea, 2013), and Wrightbus (the UK, 2014), as cited in [11]. WPT systems offer several advantages over conductive charging for EVs.

The major goal of this work is to propose a new design method and control system for a series-series (SS) topology based on systems running at resonant frequencies, to validate their feasibility and performance for light-duty EV applications operating in charging grid-to-vehicle (G2V) mode.

**Literature Review**

Wireless Power Transfer (WPT) systems for electric vehicles (EVs) represent a cutting-edge solution to meet the growing need for efficient, convenient, and user-friendly charging technologies. This section reviews the existing literature on WPT systems, focusing on their evolution, design methodologies, modeling techniques, performance analysis, and challenges.

**Evolution of Wireless Power Transfer for EVs**

The concept of WPT dates back to the pioneering work of Nikola Tesla, who envisioned the transfer of energy without wires. In recent decades, advances in power electronics and material science have enabled practical implementations of WPT systems, particularly for EV applications. Early systems were based on inductive coupling, which, while effective over short distances, faced limitations in efficiency and alignment sensitivity. Resonant inductive coupling emerged as a significant advancement, providing enhanced transfer efficiency over greater distances.Key studies, such as those by Budhia et al. (2011), investigated coil design and operational frequency to optimize power transfer, while Liu et al. (2017) explored the application of dynamic WPT for charging EVs while in motion. These foundational works paved the way for modern WPT systems capable of meeting the demands of sustainable transportation.

**Design Methodologies**

The design of WPT systems involves optimizing coil geometry, operating frequency, and materials to achieve high efficiency and reliability. Various coil shapes, including circular, rectangular, and double-sided designs, have been analyzed to reduce energy losses and mitigate misalignment issues. Researchers such as Huang et al. (2018) demonstrated the impact of advanced materials like ferrite cores and litz wires in minimizing eddy current losses and improving thermal performance.The inclusion of multi-coil configurations and modular designs has further enhanced system scalability and transfer capacity. Control algorithms for managing power flow and adjusting to load variations have also been developed, ensuring robust system performance across diverse operating conditions.

**Modeling Techniques**

Simulation tools and analytical models play a crucial role in the development of WPT systems. Finite Element Analysis (FEA) has been widely used to study magnetic field distribution, thermal behavior, and electromagnetic interference in WPT setups. MATLAB-based simulation environments enable iterative testing of design parameters, offering insights into system efficiency, alignment sensitivity, and power losses.Comparative studies, such as those by Song et al. (2020), have highlighted the effectiveness of different modeling techniques in capturing real-world challenges, such as coil misalignment and variable load conditions, thus enabling the optimization of system performance.

**Comparative Analysis of WPT Systems**

Several studies have compared inductive and resonant coupling methods to assess their suitability for EV applications. While inductive coupling is more straightforward, resonant systems provide higher efficiency over larger gaps. Additionally, static versus dynamic WPT systems have been a focal point of research, with dynamic systems offering the promise of continuous charging for vehicles in motion.Experimental setups by researchers like Wang et al. (2019) demonstrated the trade-offs between transfer distance, alignment tolerance, and power output. These insights have informed the design of next-generation WPT systems tailored for diverse EV use cases.

**Challenges and Research Opportunities**

While WPT technology holds immense promise, several challenges remain. Efficiency degradation due to

misalignment, electromagnetic interference, high system costs, and safety concerns are among the critical issues identified in the literature. Regulatory standards for WPT systems and grid integration are still under development, further complicating large-scale deployment.Emerging research opportunities include the application of metamaterials for enhanced magnetic field control, artificial intelligence for real-time alignment correction, and bidirectional charging capabilities for vehicle-to-grid (V2G) integration. Advances in these areas can significantly improve the performance, affordability, and scalability of WPT systems.
The literature highlights the rapid progress in WPT technology for EVs, emphasizing its potential to transform charging infrastructure. Building on these studies, this research proposes innovative methodologies for the design, modeling, and evaluation of WPT systems, addressing existing challenges and contributing to the advancement of sustainable transportation technologies.

**Design and Optimization Methodology for SS Topology in Wireless Power Transfer Systems**

The resonant WPT system includes magnetically coupled main and secondary coils, power electronics converters (e.g. AC/DC rectifier, DC/AC inverter), and compensation circuits.Figure 1 depicts an overall block diagram of the components and power electronics converter for Wireless power transmission from the grid to the load. The AC utility grid electricity is transformed to DC, which is subsequently turned into high-frequency AC power using an inverter. The high-frequency current in the first coil creates an alternating magnetic field, resulting in an AC voltage on the secondary coil. By resonating with the compensation circuits, the transfer power and efficiency improve dramatically. The secondary coil receives this high-frequency AC power, which is rectified to Significantly improved. The secondary coil converts high-frequency AC power into DC electricity to charge electric vehicle batteries.

The design and modeling of a wireless power transfer (WPT) system that uses **Series-Series (SS) topology** for **bidirectional power transfer**. This is a specific configuration where capacitors are connected in series with both the primary (transmitter) and secondary (receiver) coils to achieve resonance at the operating frequency. In SS topology, both the primary and secondary coils are compensated with capacitors connected in series. This configuration is favored for its ability to maintain resonance and high efficiency across varying load conditions. Unlike traditional unidirectional systems (e.g., charging EV batteries), bidirectional systems allow power to flow in both directions, Forward Mode: Power is transferred from the grid to the EV battery for charging & Reverse Mode: Power can be sent back from the EV battery to the grid (vehicle-to-grid or (V2G) or to another device.

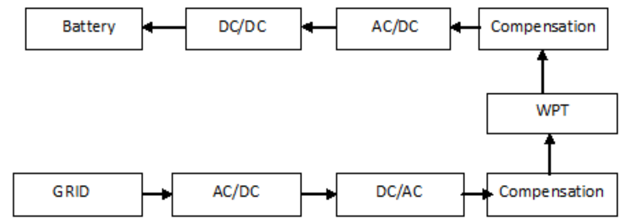


Figure 1: Block Diagram of WPT

Figure 2 depicts a bidirectional WPT system with SS-compensated topology. Figure 2 explains the methods for designing the WPT system's SS structure. Bidirectional wireless system model for SS topology. Figure 3 depicts an equivalent circuit model for a WPT system with compensation capacitors in an SS topology. To simplify, the comparable source resistance is ignored. The subscripts "1" and "2" indicate the "primary" and "secondary" coil values of inductor L, resistance R, and capacitance C. The primary circuit's source voltage is V1. RL represents the equivalent load resistance. The source current (I1) flows via the primary coil, while the load current (I2) flows through the secondary coil.

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$$k = \frac{m}{\sqrt{L_1 L_2}} \tag{1}$$

The voltage equations in Figure 3 can be written using the mutual inductance; M. *w* is the frequency of $V_1$.

$$\begin{aligned} V_1 &= \left(\frac{1}{j\omega C_1} + j\omega L_1 + R_1\right) I_1 - j\omega M I_2 \\ V_2 &= -\left(\frac{1}{j\omega C_2} + j\omega L_2 + R_2\right) I_2 + j\omega M I_1 \end{aligned} \tag{2}$$

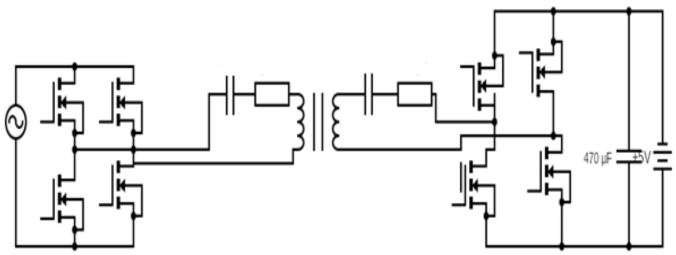


Figure 2: The bidirectional wireless system model for SS topology

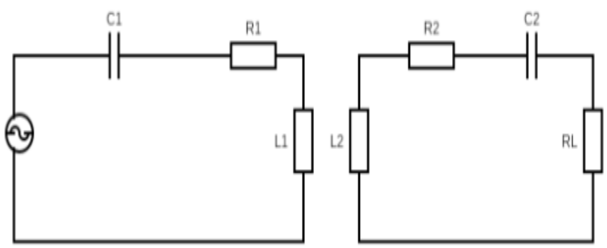


**Figure 3.** Equivalent circuit model for SS topology.

The resonant frequencies $w_0$ at the primary coil and the secondary coil are assumed to be equal

$$\omega_0 = \frac{1}{\sqrt{C_1 L_1}} = \frac{1}{\sqrt{C_2 L_2}} \qquad (3)$$

At the perfect resonant frequency *w*0, Equation (2) can be rewritten as (4).

$$\begin{aligned} V_1 &= (R_1) I_1 - j\omega M I_2 \qquad (4) \\ V_2 &= -(R_2) I_2 + j\omega M I_1 \end{aligned}$$

In Figure 3, the delivered power to the load PL and the transfer efficiency *h* at the resonant Frequency $w_0$ can be obtained as follows in Equations (5) and (6) [35]:

$$P_L = \frac{V_1^2 R_L M^2 \omega_0^2}{(R_1(R_2 + R_L) + \omega_0^2 M^2)^2} \qquad (5)$$

$$Efficiency = \frac{R_L M^2 \omega_0^2}{\left(R_1(R_2 + R_L)^2 + \omega_0^2 M^2 \, (R_2 + R_L)\right)} \qquad (6)$$

By defining the quality factor of the primary and secondary coils, $Q_1 = wL_1/R_1$, $Q_2 = wL_2/R_2$, so the transferred efficiency Equation (6) replaced by $Q_1$ and $Q_2$ can be rewritten in Equation (7):

$$Efficiency = \frac{R_L}{\left(\frac{(R_2 + R_L)^2}{R_2 Q_1 Q_2 K^2} + R_2 + R_L\right)} \qquad (7)$$

The maximum transmission efficiency of the WPT system can be derived as [35]

$$Efficiency = \frac{Q_1 Q_2 K^2}{\left(1 + \sqrt{1 + Q_1 Q_2 K^2}\right)} \qquad (8)$$

Equation (8) shows that the maximum efficiency improves as $Q_1 Q_2 K^2$ grows. It should be noted that a WPT system's maximum efficiency is determined by the product of the coupling coefficient k and the inductor quality factor Q. Thus, the primary design consideration of a WPT system is achieving the highest feasible Q and k. These two critical characteristics depend on the shape, size, and relative position of the primary and secondary coils. The primary purpose in designing a WPT system is to maximize efficiency and optimize power transfer capabilities based on operational conditions. In EV wireless charging applications, the battery is typically connected to the coil using a diode-bridge rectifier or a regulated converter. The battery can be expressed as a resistance $R_b = U_b / I_b$, where $U_b$ and $I_b$ indicate the voltage and current, respectively. Equation (9) can be used to compute the equivalent AC side resistance ($R_L$) in an SS-compensated WPT system where the battery is directly connected to the rectifier. Thus, a battery load could be turned into an equivalent resistive load [36].

$$R_L = \frac{8}{\pi} R_b \qquad (9)$$

**Design Procedures for the SS Topology WPT System**

The design and calculation process for an inductive power transfer (IPT) system involves several key steps, focusing on optimizing performance and ensuring efficient energy transfer. First, the equivalent load resistance ($R_L$) is calculated by modeling the battery's charging power and voltage. This involves finding the battery's resistance ($R_b$) using the relationship $R_b = V_{bat}^2 / P_{bat}$ $V_{bat}$ is the battery voltage and $P_{ba}$t is the power. The equivalent load resistance $R_L$ is then determined using $R_L = \frac{8}{\pi^2} R_b$ , accounting for the AC circuit characteristics.Next, the system's resonant frequency ($f_0$) is calculated, as resonance enhances energy transfer efficiency. This involves finding the angular resonant frequency ($\omega_0$) using coil resistances ($R_1$,$R_2$), mutual inductance (M), and a constant tuning factor (Kw). The relationship

$$\omega_0 = K_w \frac{\sqrt{R_1 (R_1 + R_2)}}{M}$$

is used, and $f_0 = \omega_0/\pi f$ gives the frequency. The primary and secondary capacitances ($C_1$) are determined to achieve resonance, using $C_1 = 1/\omega_0^2 L_1$ and $C_2 = 1/\omega_0^2 L_2$ are the primary and secondary inductances, respectively. The equivalent impedance of the primary circuit ($Z_1$) is then calculated, incorporating the reflected impedance due to the coupled secondary circuit: $Z1=R1+ \omega_0^2 M^2/R2+RL$.Using the impedance, the primary current ($I_1$) is found with $I_1=V_1/Z_1$ . The secondary current ($I_2$) is derived as $I_2=I_1 \text{ X } \omega_0 M / R_2+R_L$ , reflecting the coupled nature of the system.

Design considerations include choosing an appropriate current density (d) for the material to calculate the wire's cross-sectional area ($S_i$), ensuring the coil can handle the current. The voltage across the primary and secondary capacitances, $V_{c1}$ and $V_{c2}$, are calculated as $V_{c1}=I_1 \text{ X} 1/ \omega_0 C_1$ and $V_{c2}=I_2 \text{X } 1/\omega_0 C_2$, providing insight into the voltage stresses.Finally, the quality factors of the primary and secondary coils, Qp and Qs, are evaluated. These factors, given by $Q_p = \frac{L_1 R_L}{M^2 \omega_0}$ and $Q_s = \frac{\omega_0 L_2}{R_L}$ , indicate the energy efficiency and losses in the coils. These steps ensure a well-optimized IPT system, balancing efficiency, performance, and design constraints.

**Magnetic Design and Verification of Coil Parameters**

The magnetic design of coils focuses on analyzing and optimizing parameters like coil radius, number of turns, current, and spacing. These factors influence the magnetic flux density, energy transfer efficiency, and inductance. For verification, numerical methods like Finite Difference Method (FDM) or Finite Element Method (FEM) can simulate the behavior of magnetic fields to ensure the design meets the required specifications.

Objectives

1. Design Parameters:
   - Coil Radius (R): Determines the area enclosed by the coil, impacting the magnetic field strength.
   - Number of Turns (N): Affects the magnetic flux density proportionally.
   - Current (I): Drives the magnetic field strength (B).
   - Spacing between Turns: Impacts the uniformity of the field.
2. Verification Goals:
   - Verify the magnetic flux density (B) in a specified domain.
   - Analyze the magnetic flux lines to ensure proper field distribution
   - Validate the design under various current or geometric constraints.

The current distribution in the primary coil and magnetic flux lines in the air are illustrated in Figure 4 in 3D, with maximum and minimum values of flux density which is developed from the matlab code.

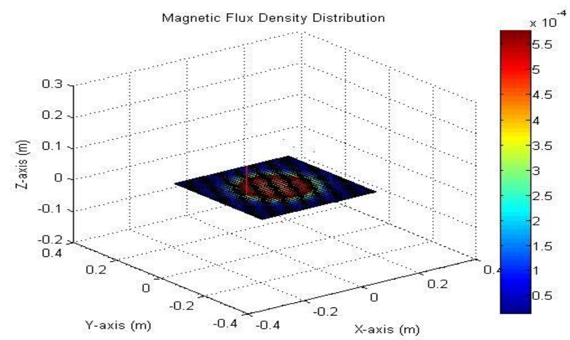


Figure 4: Current and magnetic flux density distribution in 3D.

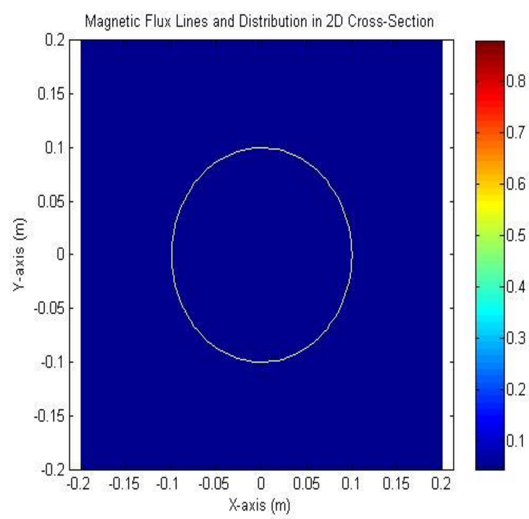


Figure 5: Magnetic flux line and distribution in 2D cross-section

Figure 5 shows a cross-section view of the 2D Magnetic flux line and distribution which is developed from the matlab code

Using the Finite Element Method (FEM) to analyze the magnetic flux distribution and flux lines involves discretizing the problem space into smaller elements and solving Maxwell's equations numerically. MATLAB provides tools such as the Partial Differential Equation (PDE) Toolbox to perform FEM simulations efficiently. This code uses the Finite Difference Method (FDM) to calculate the magnetic flux density and magnetic flux lines in a 2D plane for a current-carrying circular coil. This code calculates and visualizes the magnetic field of a current-carrying coil using Finite Difference Method (FDM). The Poisson equation is solved iteratively to find the vector potential (A), which is then used to compute the magnetic flux density (B). The results are visualized with both contour plots (for B magnitude) and vector field plots (for flux lines) it is shown in the figure 6 and Figure 7.

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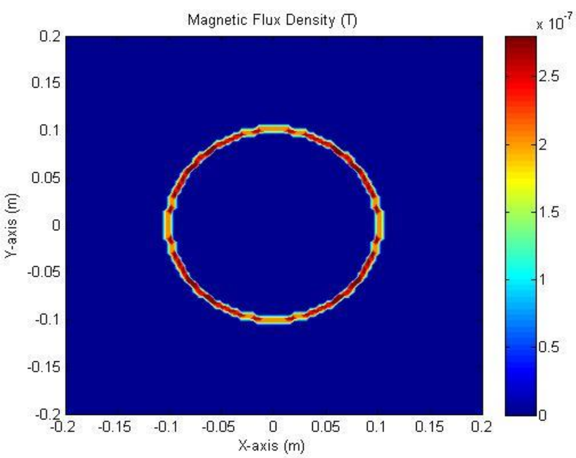


Figure 6: magnetic flux density distribution from FDM

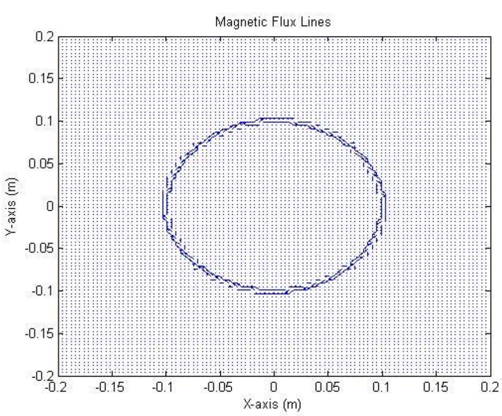


Figure 7: Magnetic flux line and distribution from FDM

**Design of Control System for a Bidirectional SS WPT System**

The grid current was actively rectified using an H-Bridge from the AC supply, operating as a single-phase PWM rectifier in G2V mode. The DC-link was powered by the H-Bridge, a single-phase inverter that functioned in square-wave mode. At a predetermined switching frequency, the primary resonant circuit is excited. The output of the secondary resonant circuit was rectified using the H-Bridge's reverse conducting diodes on the secondary side. An on-board bidirectional DC-DC converter reduced the rectified DC-link voltage to a lower battery pack voltage. This DC-DC converter functioned as a standard Buck converter in G2V mode. A hysteresis current control (HCC) was utilized to control the current on the grid side. The hysteresis band was determined using Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) as power switches, with the highest switching frequency. DC-link voltage control was used to establish the amplitude of the voltage reference value, ensuring a constant DC voltage of 250 V. The H-Bridges that powered the primary and secondary resonant circuits were set to run in square-wave mode with fixed switching frequencies. The DC-DC converter was controlled by a cascade of an inner inductor current control loop and an outer voltage battery control loop, with DC-link voltage stabilization (41).

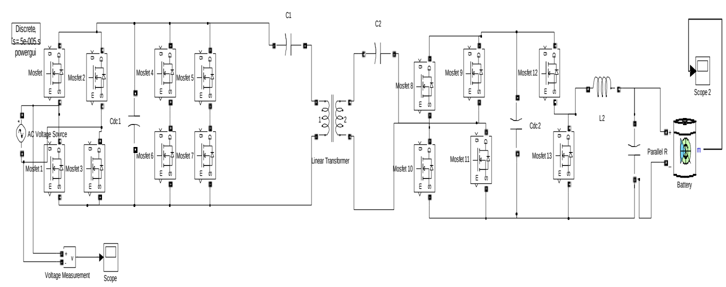


Figure 8: Matlab module for WPT system using MOSFET

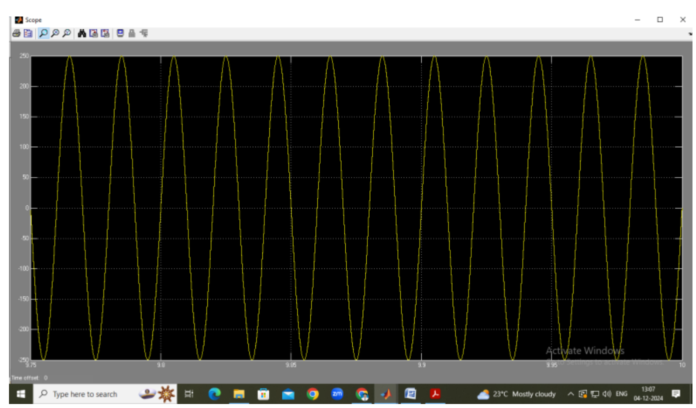

Figure 9: Input Grid Voltage of WPT system

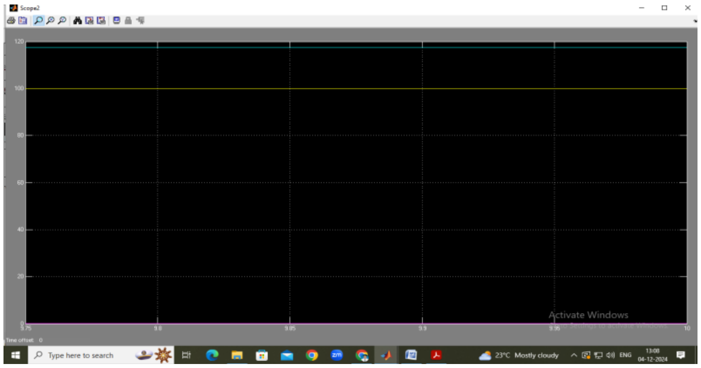

Figure 10: Output Battery Charging Voltage of WPT system

We simulated a grid-to-vehicle power transmission system to charge a 200 V lithium-ion battery pack. The charging battery power was set to 3700 watts. According to Figure 10, the average battery voltage is 100 V. Furthermore, as shown, the grid side achieved a unity power factor. The resonant circuit exhibited resonance on both the primary and secondary sides.

Figure 11 shows a simulation to evaluate the concept of the suggested architecture using a diode rectifier and a mosfet. The input single-phase AC power from the utility grid was 230 V. Each leg of the H-Bridge was connected to To lower the spike voltage of SiC MOSFETs, add a 1.5 uF snubber capacitor. Table 1 provides the simulation parameters and component breakdown. The primary focus was on implementing the WPT idea and design.Figures 12 and 13 show the AC input voltage from the grid, DC load current, and simulation waveform voltage. We tested input voltage and current using a single-phase passive rectifier.

Table 1: Parameter for the simulation Testing

| L1µH | L2µH | C1µF | C2µF | CS1µF | CS2µF | Cdc1µF |
|---|---|---|---|---|---|---|
| 332.41 | 302.24 | 47.63 | 52.37 | 1.5 | 1.5 | 4700 |

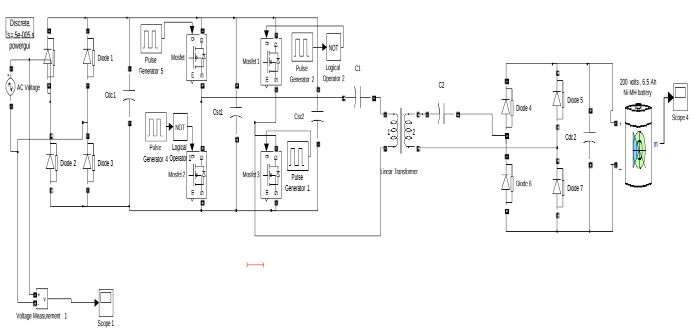

Figure 11: Matlab module for WPT system using Diode Circuit & MOSFET

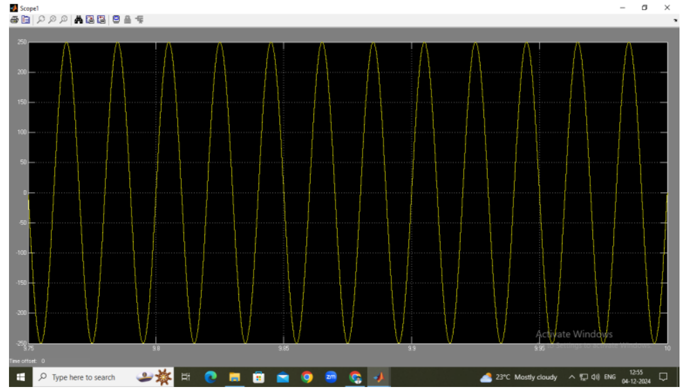

Figure 12: Input Grid Voltage of WPT system

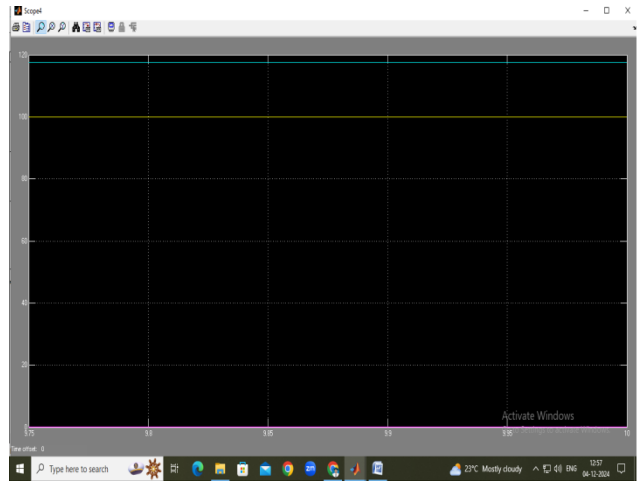

Figure 13: Output Battery Charging Voltage of WPT system

**Conclusion:**

This research presents a design optimization approach for an SS WPT system. A WPT system with SS compensation topology was designed for a 3.7 kW resonant frequency. Coil optimization was used to create the primary and secondary coil parameters, including diameters. The primary and secondary coils were constructed to achieve the highest coupling coefficient. This study presents control systems that incorporate grid-to-vehicle (G2V) operating modes using unidirectional rectifiers/inverters and DC-DC converters. Simulations and magnetic verification indicate that a WPT system is efficient for light-duty EV applications. Furthermore, a 3.7 kW WPT system simulation is performed to first confirm the WPT architecture and performance.

The investigation of creative approaches to wireless power transfer (WPT) system design for electric vehicles (EVs) has showed the potential to boost energy transfer efficiency, system dependability, and design optimization. The energy transfer efficiency between the transmitter and receiver coils has been greatly increased by using modern coil design approaches such as SS (Series-Series) architecture and new magnetic flux management techniques. This is critical for lowering energy losses and maintaining the longevity of EV charging systems. The exact modeling of magnetic flux distribution using numerical approaches (such as the Finite Difference Method and Biot-Savart equation) and FEM simulations has resulted in a better understanding and optimization of magnetic coupling between coils. Uniform magnetic flux distribution is required to enhance power transfer while reducing leakage fields.

The combination of 2D cross-sectional and 3D spatial modeling has revealed new insights into flux density distribution. This has enabled the accurate prediction of system performance under real-world operating situations. The development of bidirectional WPT systems, as shown in SS topologies, illustrates the capability of charging and discharging (V2G applications). This adds to smarter, more integrated energy systems. Wireless EV charging solutions eliminate the need for physical connectors, increasing convenience, lowering maintenance costs, and improving the charging infrastructure's lifespan. This is consistent with the global goals of lowering carbon emissions and encouraging renewable energy consumption. This study provides up possibilities for additional investigation in areas such as: Real-time control algorithms improve dynamic charging capabilities for moving EVs. Renewable energy sources are being integrated into WPT systems to provide environmentally friendly charging options. Experimental verification of theoretical and simulation results for large-scale deployment. In conclusion, the unique ideas described in this study help to advance the state-of-the-art in WPT system design for EVs, making them more efficient, dependable, and adaptive to future technical and environmental concerns.

**References**

1. Hegazy, O.; Barrero, R.; Van Mierlo, J.; Lataire, P.; Omar, N.; Coosemans, T. An advanced power electronics interface for electric vehicles applications. IEEE Trans. Power Electron. **2013**, 28, 5508–5521. [CrossRef]

2. ACEA—European Automobile Manufacturers' Association. ACEA Report. Available online: http://www. acea.be/publications (accessed on 12 June 2018).

3. Miceli, R.; Viola, F. Designing a sustainable university recharge area for electric vehicles: Technical and economic analysis. Energies **2017**, 10, 1604. [CrossRef]

4. Brenna, M.; Dolara, A.; Foiadelli, F.; Leva, S.; Longo, M. Urban scale photovoltaic charging stations for electric vehicles. IEEE Trans. Sustain. Energy **2014**, 5, 1234–1241. [CrossRef]

5. Longo, M.; Zaninelli, D.; Viola, F.; Romano, P.; Miceli, R.; Caruso, M.; Pellitteri, F. Recharge stations: A review. In Proceedings of the 11th International Conference on Ecological Vehicles and Renewable Energies, EVER 2016, Monte Carlo, Monaco, 6–8 April 2016.

6. Covic, G.A.; Boys, J.T. Inductive Power Transfer. Proc. IEEE **2013**, 101, 1276–1289. [CrossRef]

7. Covic, G.A.; Boys, J.T. Modern Trends in Inductive Power Transfer for Transportation Applications.IEEE J. Emerg. Sel. Top. Power Electron. **2013**, 1, 28–41. [CrossRef]

8. Kalwar, K.A.; Aamir, M.; Mekhilef, S. Inductively coupled power transfer (ICPT) for electric vehicle charging—A review. Renew. Sustain. Energy Rev. **2015**, 47, 462–475. [CrossRef]

9. Bosshard, R.; Kolar, J.W. Inductive Power Transfer for Electric Vehicle Charging: Technical challenges andtradeoffs. IEEE Power Electron. Mag. **2016**, 3, 22–30. [CrossRef]

10. Rogge, M.; Wollny, S.; Sauer, D. Fast Charging Battery Buses for the Electrification of Urban Public Transport—A Feasibility Study Focusing on Charging Infrastructure and Energy Storage Requirements. Energies **2015**, 8, 4587–4606. [CrossRef]

11.Andersson,M. Energy Storage Solutions for Electric Bus Fast Charging Stations. Master's Thesis, Uppsala University, Uppsala, Sweden, 2017.

12. Ning, P.; Miller, J.M.; Onar, O.C.; White, C.P. A Compact Wireless Charging System for ElectricVehicles. In Proceedings of the Energy Conversion Congress and Exposition (ECCE), Denver, CO, USA, 15–19 September 2013; IEEE: Piscataway, NJ, USA, 2013; pp. 3629–3634.

13. Garcés Quílez, M.; Abdel-Monem, M.; El Baghdadi, M.; Yang, Y.; Van Mierlo, J.; Hegazy, O. Modelling, Analysis and Performance Evaluation of Power Conversion Unit in G2V/V2G Application—A Review. Energies **2018**, 11, 1082. [CrossRef]

14. Miller, J.M.; Jones, P.T.; Li, J.M.; Onar, O.C. ORNL experience and challenges facing dynamic wireless power
charging of EV's. IEEE Circuits Syst. Mag. **2015**, 15, 40–53. [CrossRef]

15. Li, S.; Liu, Z.; Zhao, H.; Zhu, L.; Shuai, C.; Chen, Z. Wireless Power Transfer by Electric Field Resonance and
Its Application in Dynamic Charging. IEEE Trans. Ind. Electron. **2016**, 63, 6602–6612. [CrossRef]

16. Li, W.; Zhao, H.; Deng, J.; Li, S.; Mi, C.C. Comparison Study on SS and double-sided LCC compensation
topologies for EV/PHEVWireless Chargers. IEEE Trans. Veh. Technol. **2016**, 65, 4429–4439. [CrossRef]

17. Sohn, Y.H.; Choi, B.H.; Lee, E.S.; Lim, G.C.; Cho, G.H.; Rim, C.T. General Unified Analyses of Two-Capacitor
Inductive Power Transfer Systems: Equivalence of Current-Source SS and SP Compensations. IEEE Trans. Power Electron. **2015**, 30, 6030–6045. [CrossRef]

18.Aditya, K.;Williamson, S.S. Comparative Study of Series-Series and Series-Parallel Compensation Topologies
for Electric Vehicle Charging. In Proceedings of the 2014 IEEE 23rd International Symposium on Industrial Electronics (ISIE), Istanbul, Turkey, 1–4 June 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 426–430.

19. Zhang, W.; Wong, S.C.; Tse, C.K.; Chen, Q. Analysis and comparison of secondary series-and parallel-compensated inductive power transfer systems operating for optimal efficiency and load-independent voltage-transfer ratio. IEEE Trans. Power Electron. **2014**, 29, 2979–2990. [CrossRef]

20. Stielau, O.H.; Covic, G.A. Design of loosely coupled inductive power transfer systems. In Proceedings of the 2000 International Conference on Power System Technology, Perth,WA, Australia, 4–7 December 2000; IEEE: Piscataway, NJ, USA, 2000; pp. 85–90.

21. Yuan, X.; Liao, Y. Compensation topology for flat spiral coil inductive power transfer systems. IET Power Electron. **2015**, 8, 1893–1901. [CrossRef]

22. Neath,M.J.; Swain,A.K.;Madawala,U.K.; Thrimawithana,D.J.An optimal PIDcontroller for a bidirectional inductive
power transfer system using multiobjective genetic algorithm. IEEE Trans. Power Electron. **2014**, 29, 1523–1531.
[CrossRef]

23. Wu, H.H.; Covic, G.A.; Boys, J.T.; Robertson, D.J. A series-tuned inductive-power-transfer pickup with
a controllable AC-voltage output. IEEE Trans. Power Electron. **2011**, 26, 98–109. [CrossRef]

24. Zhang, W.; Wong, S.C.; Tse, C.K.; Chen, Q. A study of sectional tracks in roadway inductive power transfer system. In Proceedings of the 2011 IEEE Energy Conversion Congress and Exposition, Phoenix, AZ, USA, 17–22 September 2011; IEEE: Piscataway, NJ, USA, 2011; pp. 822–826. Chopra, S. Contactless Power Transfer for Electric Vehicle Charging Application. Master's Thesis, Delft University of Technology, Delft, The Netherlands, 2011.

26. Prasanth, V.Wireless Power Transfer for E-Mobility. Master's Thesis, Delft University of Technology, Delft,

The Netherlands, 2012.
27. Chen, L.; Liu, S.; Zhou, Y.C.; Cui, T.J. An optimizable circuit structure for high-efficiency wireless power transfer. IEEE Trans. Ind. Electron. **2013**, 60, 339–349. [CrossRef]
28. Villa, J.L.; Sallán, J.; Sanz Osorio, J.F.; Llombart, A. High-misalignment tolerant compensation topology for ICPT systems. IEEE Trans. Ind. Electron. **2012**, 59, 945–951. [CrossRef]
29. Bosshard, R.; Kolar, J.W. Fundamentals and Multi-Objective Design of Inductive Power Transfer Systems. In Proceedings of the 30th Applied Power Electronics Conference and Exposition (APEC 2015), Charlotte, NC, USA, 15–19 March 2015.
30. Zheng, C.; Lai, J.S.; Chen, R.; Faraci,W.E.; Zahid, Z.U.; Gu, B.; Zhang, L.; Lisi, G.; Anderson, D. High Efficiency
Contactless Power Transfer System for Electric Vehicle Battery Charging Application. IEEE J. Emerg. Sel. Top. Power Electron. **2014**, 6777, 1–11. [CrossRef]
31. Ruiz-Rodriguez, F.J.; Hernández, J.C.; Jurado, F. Voltage behaviour in radial distribution systems under the uncertainties of photovoltaic systems and electric vehicle charging loads. Int. Trans. Electr. Energy Syst. **2018**, 28, 1–23. [CrossRef]
32. Hernández, J.C.; Ruiz-Rodriguez, F.J.; Jurado, F. Modelling and assessment of the combined technical impact of electric vehicles and photovoltaic generation in radial distribution systems. Energy **2017**, 141, 316–332. [CrossRef]
33. Sanchez-Sutil, F.; Hernández, J.C.; Tobajas, C. Overview of electrical protection requirements for integration of a smart DC node with bidirectional electric vehicle charging stations into existing AC and DC railway grids. Electr. Power Syst. Res. **2015**, 122, 104–118. [CrossRef]
34.Hernandez, J.C.; Sutil, F.S.; Vidal, P.G. Protection of a multiterminal DC compact node feeding electric vehicles on electric railway systems, secondary distribution networks, and PV systems. Turkish J. Electr. Eng. Comput. Sci. **2016**, 24, 3123–3143. [CrossRef]
35. Li, S.; Mi, C. Wireless Power Transfer for Electric Vehicle Applications. IEEE J. Emerg. Sel. Top. Power Electron.
**2015**, 3, 4–17. [CrossRef]
36. Steigerwald, R.L. Comparison of Half-Bridge Resonant Converter Topologies. IEEE Trans. Power Electron. **1988**, 3, 174–182. [CrossRef]
37. Sallan, J.; Villa, J.L.; Llombart, A.; Sanz, J.F. Optimal Design of ICPT Systems Applied to Electric Vehicle Battery Charge. IEEE Trans. Ind. Electron. **2009**, 56, 2140–2149. [CrossRef]
38. Aditya, K.; Williamson, S.S. Design considerations for loosely coupled inductive power transfer (IPT) system for electric vehicle battery charging—A comprehensive review. In Proceedings of the 2014 IEEE Transportation Electrification Conference and Expo (ITEC), Dearborn, MI, USA, 15–18 June 2014; IEEE: Piscataway, NJ, USA, 2014; pp. 1–6.
39. Benomar, Y.; El Baghdadi, M.; Hegazy, O.; Yang, Y.; Messagie, M.; Mierlo, J. Van Design and modeling of V2G
inductive charging system for light-duty Electric Vehicles. In Proceedings of the 2017 Twelfth International Conference on Ecological Vehicles and Renewable Energies (EVER), Monte Carlo, Monaco, 11–13 April 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 1–7.
40. El Baghdadi, M.; Benomar, Y.; Hegazy, O.; Yang, Y.; Van Mierlo, J. Design approach and interoperability analysis of wireless power transfer systems for vehicular applications. In Proceedings of the 2016 18th European Conference on Power Electronics and Applications (EPE'16 ECCE Europe), Karlsruhe, Germany, 5–9 September 2016; IEEE: Piscataway, NJ, USA, 2016; pp. 1–11.
41.Yang, Y.; Benomar, Y.; El Baghdadi, M.; Hegazy, O.; Van Mierlo, J. Design, Modeling and Control of a BidirectionalWireless Power Transfer for Light-Duty Vehicles: G2V and V2G Systems. In Proceedings of the 2017 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe), Warsaw, Poland, 11–14 September 2017; IEEE: Piscataway, NJ, USA, 2017; pp. 1–12.