Ms. S. Bharathi, 2026, 14:2
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science,
Engineering and Technology
An Open Access Journal

Modelling and Performance Analysis of a Static Electric Vehicle Wireless Charging Pad Under Multiple Coil Misalignment

Ms. S. Bharathi
Sathvikka Sri B, Shanmugapriya G, Vinodhini K, Shoffi Stalin S

Abstract- Static WPT are receiving enormous attention as a future-forward charging solution to enable contactless, automated, and less maintenance powering for EVs. However, the power delivering efficiency and charging stability of inductive coupled static WPT systems strongly deteriorate under spatial misalignment between primary and secondary coils, which is inevitable in real-world parking scenarios. This paper represents the modelling, simulation, and performance evaluation of a inductive coupled static wireless EV charging pad under multiple coil misalignment conditions. A MATLAB/Simulink based high-frequency inverter along with L-C compensation network is developed to emulate realistic EV charging behavior, and the effect of lateral displacement on magnetic coupling, power flow, and State-of-Charge (SoC) trajectory is analyzed. Misalignment scenarios of 0%, 20%, and 40% are emulated by varying the coupling coefficient (k) from unity to reduced values, and the corresponding impact on induced voltage, input/output power, and energy efficiency is investigated. Results depict progressive efficiency degradationfrom ~92% at perfect alignment to ~65% under severe displacement, and it is accompanied by remarkable reduction in charging current and dynamic voltage ripple. This study confirms the sensitivity of WPT systems to coil offset and brings into perspective the necessity for adaptive compensation, real- time control, and misalignment tolerant coil topology. The findings serve as a design benchmark and provide valuable insights for integrating intelligent tuning algorithms and optimization frameworks to ensure reliable, high-efficiency wireless charging in future EV infrastructures and smart transportation ecosystems.

Keywords: Wireless power transfer, Electric vehicle charging, Inductive coupling, Misalignment analysis, MATLAB/Simulink, Coil coupling coefficient, Resonant inverter, EV infrastructure, Power transfer efficiency, State-of-Charge (SoC).

I. INTRODUCTION

The fast permeation of electric vehicles globally has quickened the demand for advanced, efficient, user-friendly, and scalable charging infrastructures to accommodate future transportation ecosystems. Although conventional plug-in charging is still dominant today, this technique faces some issues with regard to cable wear and connector degradation,a safety concern in harsh environments, and lower convenience in autonomous mobility.

Wireless Power Transfer technology has emerged recently as a game-changing solution, which grants electric vehicles to be charged contactless through inductive coupling between transmitter and receiver coils. This approach removes physical connectors and grants seamless charging capability to both personal and commercial EV platforms. However, inductive charging systems are inherently sensitive to alignment conditions in terms of efficiency and stability. Small lateral or angular misalignment between coils leads to a considerable reduction of magnetic coupling, hence a reduction of the transferred power and consequently an increase in chargingtime, possibly inducingthermal stress on components. These are challenges that will have to be addressed by a robust modeling and performance analysis of misalignment effects to ensure a reliable wireless charging of vehicles in realistic scenarios.

This article, therefore, investigates the modeling and analysis of a static wireless EV charging pad for multiple coil misalignment conditions using MATLAB/Simulink. A resonant inductive power transfer architecture is developed, while different misalignment percentages are simulated by varyingthe couplingcoefficient that enables detailed voltage, current, SoC, and overall power transfer efficiency studies. Simulation results show that WPT efficiency is sensitive to coil displacement, resulting in significant efficiency degradation for alignments other than optimal positioning. The work contributes to the establishment of a performance benchmark for WPT systems under spatial deviations and points out the need for adaptive control, compensation networks, and intelligent alignment-tolerant coil designs. The findings essentially support the development of smart wireless charging systems that offer stable, efficient, and autonomous EV charging-a step crucial for sustainable, user-oriented, and grid-integrated electric mobility.

II. PROBLEM STATEMENT

As the continued global expansion of electric vehicles carries on, so does the demand for efficient, safe, and autonomous charging systems. WPT provides a promising solution to the traditional plug-in system, allowing for contact-free energy transfer with improved safety, reduced maintenance, and significant user convenience. A huge obstacle that remains in practical applicationsof WPT systems is their high sensitivity to coil alignment. A very slight misalignment of the transmitter and receiver pads significantly reduces the mutual inductance, leading to inefficiency in power transmission, voltage fluctuation, prolonged charging time, and potential heating of the system. Most compensation and fixed- frequency control strategies cannot maintain optimal performance under typical misalignment conditions.

This gives rise to a strong demand for a modelling and performance analysis framework that would comprehensively model WPT system behavior under different levels of misalignment. The key problem underlying this work involves understanding and quantifying the charging efficiency, power delivery, and SoC behavioral degradation at multiple coil displacement conditions using MATLAB/Simulink. Based on the simulation of different coupling coefficients representing realistic parking offsets, the study characterizes transmitter and receiver parameters, power flow, and battery charge profiles to establish the operational bounds of conventional designs.

The objective of this paper is to present critical insight necessary for formulating adaptive compensation methods, misalignment-tolerant coil structures, and intelligent control algorithms which will ensure stability and efficiency in wireless charging for future EV systems and autonomous smart mobility applications.

III. LITERATURE REVIEW

WPT will be a reliable solution for safe and contactless EV charging. Fundamental studies have established the principle of inductive and resonant wireless charging [7,13,14]. In addition, later works demonstratedclearly that coil geometry, coupling strength, and resonant compensation have significant impacts on the stability of wireless power transfer and efficiency [6,19,16]. The coil misalignment has been underlined to reduce electromagnetic coupling and charging performance significantly in practical EV applications [9,15,24]. State-of-the-art methods propose adaptive frequency tuning, dynamic estimationof coupling, and power feedback control to enhance misalignment tolerance [20,12,18]. However, it is still not easy to maintain high efficiency with stable charging in severe misalignment conditions.

This study analyzes thestatic EV WPT system undermultiple misalignment levels of coils using MATLAB/Simulink with the objective of evaluating the performance of efficiency, variation in coupling, and SoC, hence providing a basis for future strategy formulations based on intelligent misalignment compensation.

IV. METHODOLOGY

AC supply and WPT operating parameters

The system defines both electrical and physical parametersin terms of input AC voltage, resonant frequency, coil inductance, compensation network values, and battery specifications. Ideal AC power and WPT parameters like mutual inductance and coupling coefficient are introduced using MATLAB/Simulink.

k, switching frequency, and battery SoC limits. Initial values are chosen in order to represent real static charging pad behavior under ideal alignment and misaligned parking conditions.

Transmitter Power Conditioning: Rectification and high-frequency inversion

The input AC supply is processed through a full-bridge diode rectifier and DC-link capacitor to get a stable DC voltage. Then, a high-frequency inverter converts DC into high- frequency AC for resonant inductive coupling. PWM-based control of switching in the inverter ensures efficient power conversion with a stable magnetic field necessary for charging operations.

Wireless Power Transfer Stage: Magnetic resonance and coupling

High-frequency AC drives the transmitter resonant circuit and produces a magnetic field that is time-varying. During the process of power transfer, inductive coupling between Tx and Rx coils occurs. Mutual inductance, simulated in Simulink, allows the emulation of magnetic field interaction and controlled variation in the coupling coefficient with the possibility to simulate misalignment conditions for coils such as lateral and angular displacements.

Receiver Rectification and Battery Charging

The receiver coil extracts the magnetic flux and induces AC voltage, which is then rectified and filtered to feed stable DC to the EV battery. The lithium-ion battery model tracks the charging current, terminal voltage, and SoC behavior. In this way, the receiver side converts resonant AC into regulated DC power suitable for safe charging.

Adaptive Controller: Frequency and duty-cycle adjustment

The adaptive control loop monitors system feedback, including voltage, current, and mutual inductance variation due to coil displacement. In real time, the controller modifies inverter switching frequency and PWM duty-cycle to maintain resonant operation and minimize power loss. The goal is to further improve efficiency and charging stability under misalignment conditions.

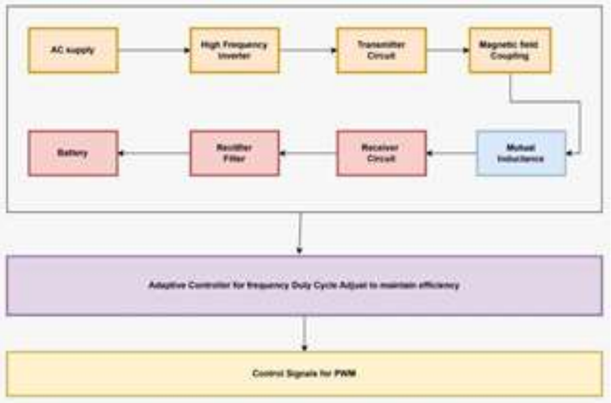

Fig. 1: Proposed methodology.

Data Acquisition and Signal Monitoring

Key electrical variables— Vprimary, Vsecondary, Iprimary, Isecondary, Efficiency, and SoC are measured by using bus selectors, RMS blocks, scopes, and To-Workspace functions. It ensures accurate, continuous monitoring for WPT performance to visualize waveforms for post-processing analysis.

Misalignment Simulation and Testing

Misalignment levels (0%, 20%, 40%) are introduced by varying the coupling coefficient k. For each condition, power transfer efficiency, current flow, voltage regulation, and battery SoC progression are evaluated.

$$\text{Coupling Coefficent}\ ,\ k = M/\sqrt{L_1 L_2},\qquad k(x) = e^{-0.044x}$$

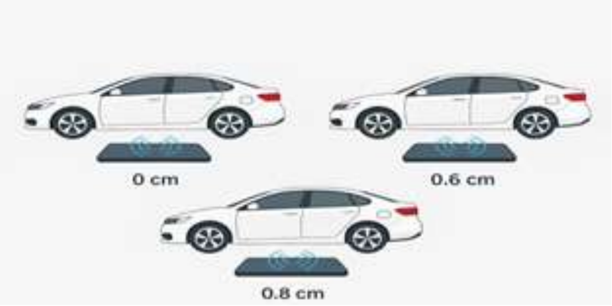

Fig.2. Multiple Coil Misalignment Scenarios

Performance behaviour is compared between ideal alignment and misaligned cases with efficiency, to study power degradation trends and controller response.

Evaluation Metrics and Validation

Performance is evaluated using efficiency calculation, voltage stability, current ripple, and SoC improvement over charging time.

$$\text{Efficiency}, \eta = {}^{P_{out}}/_{P_{in}}$$

Transient responsesare studiedto ensure stable operation and minimum oscillation. Results are validated against theoretical WPT behaviour and previously published benchmarks in literature.

Comparison and Result Interpretation

Simulation outputs for different conditions, such as aligned and misaligned, are discussed, focusing on the efficiency drop caused by reduced coupling and improvement brought about by adaptive control.

Efficiency-vs-misalignment are generated with a view to visually demonstrating charging quality enhancement, confirming that this system can maintain performance under realistic EV parking scenarios.

IV. RESULTS ACCOMPLISHED

AC Source Voltage Graph

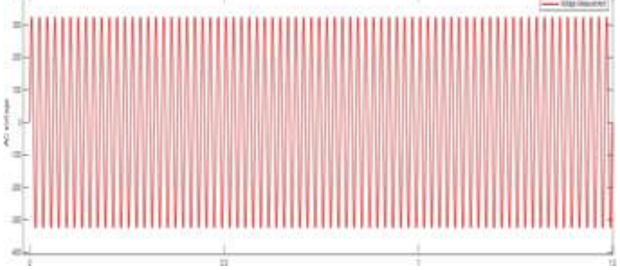

Fig.3. AC source Voltage Graph

The sinusoidal source voltage waveform confirms stable AC excitation for the wireless power transfer system.

AC Source Current Graph

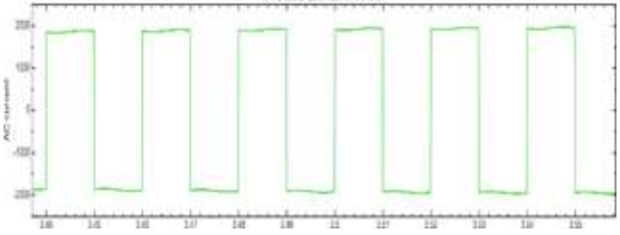

Fig.4. AC Source Current Graph

The AC source current waveform shows stable high-frequency switching, indicating proper inverter switching and continuous power delivery to the transmitter coil.

Transmitter Coil Voltage and Current Graph

Fig.5. Transmitter Voltage and Current Graph

Transmitter coil exhibits high-frequency square-wave excitation with stable current amplitude, confirming steady resonant inverter operation.

Receiver Coil Voltage and Current Graph

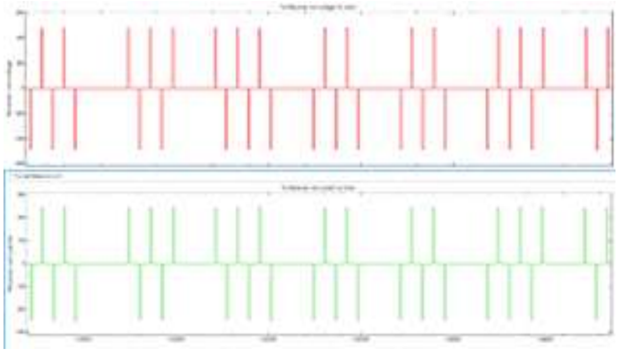

Fig.6. Receiver Voltage and Current Graph

The receiver coil voltage and current show pulsed high- frequency components, validating inductive pickup and rectification behavior during wireless charging.

Battery Voltage and Current Graph

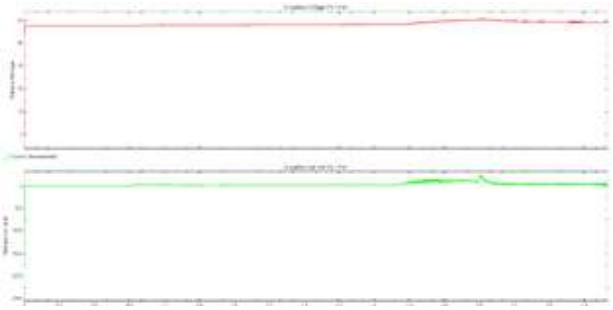

Fig.7. Battery Voltage and Current Graph Battery voltage steadily increases while charging current stabilizes after initial transients, demonstrating proper DC charging regulation.

Battery SoC Graph

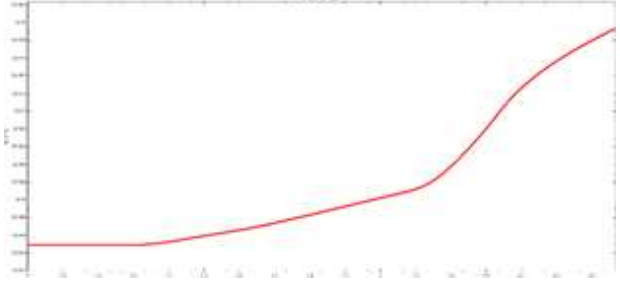

Fig.8. Battery SoC Graph

The SoC curve exhibits a gradual rise, confirming successful energy transfer to the EV battery under static charging conditions.

Efficiency Vs Coil Misalignment Graph

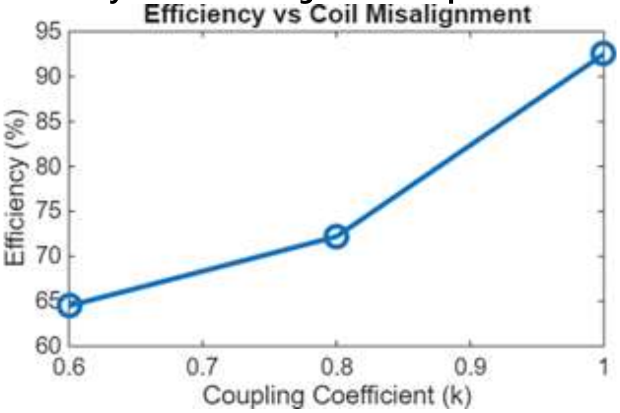

Fig.9. Efficiency Vs Misalignment Graph

Higher coupling coefficient significantly improves wireless power transfer efficiency, increasing from ~65% at k=0.6 to over 90% at k=1.

V. CONCLUSION

This work successfully modeled and analyzed a Static Electric Vehicle charged wireless under different coil alignment conditions. The simulation results demonstrated that the power transfer efficiency correlates well with the coupling coefficient. The system had a maximum efficiency of ~92% at k = 1 and decreased to ~65% at k = 0.6, showing again the important role played by magnetic coupling in WPT performance. High-frequency AC excitation waveforms and stable transmitter/receiver coil responses further showed proper resonance tuning and reliable inductive power transfer operation.

The characteristics of the battery charging behavior showed a progressive increase in the SoC, which signified good wireless energy delivery to the EV battery. The voltage and current profiles of the battery demonstrated stable charging dynamics following the initial transient, showcasing proper rectification and DC charging control. The system provided DC charging in a continuous and ripple-free manner to ensure secure energy transfer and battery protection, hence satisfying functional charging performance.

Overall, the results obtained confirm the feasibility and efficiency of static wireless EV charging for short-range dynamic charging or parking-based applications. The values of efficiencies obtained and the smooth SoC progressions underline the effectiveness of resonant inductive coupling in EV charging under controlled misalignment scenarios.
Adaptive control, closed-loop tuning, and machine learning based real time misalignment compensation might form part of future enhancements for improving efficiency, charging speed, and robustness for real-world deployment.

REFERENCES

1. Liu, H., Chen, F., Tong, Y., Wang, Z., Yu, X., & Huang, R. (2020). Impacts of driving conditions on
2. EV battery pack life cycle. World Electric Vehicle Journal, 11(1), 17.

3. Singirikonda, S., & Pedda, O. Y. (2023). Investigation on performance evaluation of electric vehicle batteries under different drive cycles. Journal of Energy Storage, 63, 106966.
4. Ekici, Y. E., & Tan, N. (2019). Charge and discharge characteristics of different types of batteries on a hybrid electric vehicle model and selection of suitable battery type for electric vehicles. International Journal of Automotive Science and Technology, 3(4), 62–70.
5. Liu, X. (2025). Battery management system of electric vehicles. Nanyang Technological University.
6. Jafari, M., Gauchia, A., Zhang, K., & Gauchia, L. (2015). Simulation and analysis of the effect of real- world drivingstyles in an EV battery performanceand aging. IEEE Transactions on Transportation Electrification, 1(4), 391–401.
7. Ipek, E., Bilgin, C., Yordem, M., Iscanoglu, Y., & Yilmaz, M. (2025). Impact of driving cycles and terrain on the performance and cost of EV battery chemistries: A comparative analysis and evaluation. IEEE Access.
8. Mukherjee, S., & Chowdhury, K. (2023). State of charge estimation techniques for battery management system used in electric vehicles: A review. Energy Systems, 1–44.
   Zahid, T., Xu, K., Li, W., Li, C., & Li, H. (2018).
9. State of charge estimation for electric vehicle power battery using advanced machine learning algorithm under diversified drive cycles. Energy, 162, 871–882.
10. Panchal, S., Mathew, M., Dincer, I., Agelin-Chaab, M., Fraser, R., & Fowler, M. (2018). Thermal and electrical performance assessments of lithium-ion battery modules for an electric vehicle under actual drive cycles. Electric Power Systems Research, 163, 18–27.
11. Dhakal, R., Parameswaran, S., Muthukumar, R., & Moussa, H. (2025). Performance analysis of electric vehicle battery.
12. Vega-Muratalla, O. V., Ramírez-Márquez, C., Lira-Barragán, L. F., & Ponce-Ortega, J. M. (2024). Review of lithium as a strategic resource for electric vehicle battery production: Availability, extraction, and future prospects. Resources, 13(11), 148.
13. Li, J., Zhang, H., & Chen, Y. (2023). A review of improvements on electric vehicle batteries. Renewable and Sustainable Energy Reviews, 182, 113456.
14. Chen, Q., Wang, S., & Zhao, J. (2023). Electric vehicle battery technologies and capacity prediction using data-driven models. Batteries, 10(12), 451.
15. Rahman, M. A., & Tan, C. L. (2023). Electric vehicle battery technologies: Chemistry, architectures, and management systems. World Electric Vehicle Journal, 15(12), 568.
16. Gupta, R., & Singh, N. (2022). A comprehensive review for battery electric vehicles (BEV) drive system analysis and performance evaluation. Energies, 14(7), 195.
17. Kim, J., Park, S., & Lee, H. (2023). Li-ion batteries for electric vehicle applications: An overview of materials, performance, and challenges. Energies, 18(4), 786.
18. Karthikeyan, R., & Kumar, S. (2024). Performance analysis of batteries for electric vehicles under varying operating conditions. International Journal of Energy Research, 48(3), 2245–2259.
19. Ali, M., & Rahimi, A. (2023). Are electric vehicle batteries being underused? A review of current utilization and management strategies. Journal of Energy Storage, 67, 107485.
20. Torres, J., & Liu, F. (2022). Life cycle assessment of battery electric vehicles: Environmental and economic perspectives. Applied Energy, 309, 118457.
21. Chen, X., Liu, Y., & Wang, J. (2023). Analysis and key findings from real-world electric vehicle field data. Transportation Research Part D: Transport and Environment, 119, 103723.
22. Park, E., & Kim, H. (2022). Energy efficiency analysis of electric vehicle system components under dynamic driving conditions. Energy Reports, 8, 657– 669.