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# Operational Performance Study of a Contactless Electric Vehicle Charging System

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## ABSTRACT

The rapid growth of electric vehicles requires efficient charging solutions that offer greater convenience and operational reliability compared to conventional wired systems. Wireless charging technology provides a promising alternative; however, its performance should be evaluated under different operating conditions to ensure its practical applicability. This study analyses the performance of a wireless charging station for electric vehicles based on inductive power transfer principles. The main objective is to evaluate system efficiency, power transfer capability, and operational stability under different coil alignment and distance conditions. The method involves experimental testing of a prototype system consisting of a high-frequency converter, transmitter and receiver coils, and a microcontroller-based control unit. Performance measurements such as output power, charging efficiency, and power loss are recorded under different misalignment levels. The results show that maximum efficiency is achieved when the transmitter and receiver coils are properly aligned, while the efficiency decreases with increasing displacement. Despite this variation, the system maintains stable operation and shows improved user convenience compared to conventional plug-in charging methods. The study concludes that wireless EV charging systems are practical and efficient, and that further improvements are needed to increase the alignment tolerance and power delivery efficiency.

## 1. INTRODUCTION

The electrification of transportation systems represents a fundamental shift in global energy consumption patterns, driven by environmental concerns, policy incentives, and technological innovation. Electric vehicles (EVs) are increasingly viewed as a viable solution to reduce greenhouse gas emissions and dependence on fossil fuels (Zhang et al., 2023). However, the effectiveness of EV adoption is strongly influenced by the availability and performance of charging infrastructure. Conventional wired charging systems, despite their widespread use, suffer from several inherent limitations such as connector degradation, exposure to environmental conditions, and user inconvenience (Patil & Kulkarni, 2022).

Wireless charging, also referred to as contactless charging, and eliminates the need for physical connectors by transferring power through electromagnetic fields. This approach enhances safety, reduces maintenance, and improves user experience. Inductive power transfer (IPT) is the most widely adopted method in wireless EV charging due to its relative

simplicity and efficiency (Li et al., 2024). Despite its advantages, IPT systems are highly sensitive to coil alignment, air-gap variations, and electromagnetic interference, which can significantly affect performance.

The present study aims to investigate the operational characteristics of a contactless EV charging system under realistic conditions. Emphasis is placed on analyzing how spatial misalignment impacts efficiency and power transfer, which are critical parameters for real-world implementation. The research adopts an experimental methodology supported by analytical insights to bridge the gap between theoretical design and practical application.

## 2. SYSTEM ARCHITECTURE AND WORKING PRINCIPLE

The wireless charging system developed in this study is based on inductive coupling between two coils: a transmitter coil embedded in the ground and a receiver coil mounted on the vehicle.

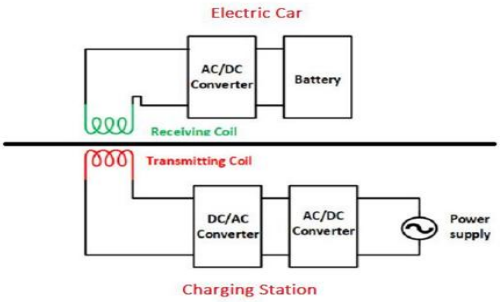


**Figure 1:** Conceptual Architecture of Contactless Electric Vehicle Charging System

The system comprises four major components:

- High-Frequency Power Converter – Converts AC supply into high-frequency AC signals suitable for efficient inductive coupling.
- Transmitter Coil Assembly – Generates a time-varying magnetic field.
- Receiver Coil Assembly – Captures the magnetic flux and converts it back into electrical energy.
- Control and Monitoring Unit – Regulates voltage, current, and safety parameters.

The working principle is governed by electromagnetic induction. When alternating current flows through the transmitter coil, it generates a magnetic field that induces a voltage in the receiver coil. The efficiency of this transfer depends on mutual inductance, which is highly sensitive to alignment and distance between coils (Kumar et al., 2023).

Resonant compensation circuits are incorporated to enhance power transfer efficiency by minimizing reactive losses. The system operates at a resonant frequency typically in the range of 20–100 kHz, ensuring optimal energy transfer.

## 3. EXPERIMENTAL METHODOLOGY AND SETUP

To evaluate the operational performance, a prototype wireless charging system was constructed and tested under controlled laboratory conditions.

### *A. Prototype Configuration*

**Table 1**: The system specifications are summarized

| Parameter | Value |
|---|---|
| Input Voltage | 230 V AC |
| Operating Frequency | 50 kHz |
| Coil Diameter | 200 mm |
| Air Gap Range | 5–25 mm |
| Output Power | 500 W |
| Control Unit | Microcontroller-based |

### *B. Testing Procedure*

The experimental evaluation involved varying two key parameters:

- Lateral Misalignment (0–100 mm)
- Vertical Distance (5–25 mm)

For each configuration, the following measurements were recorded:

- Output power (W)
- Input power (W)
- Efficiency (%)
- Thermal loss (°C rise)

### *C. Data Acquisition*

Sensors were integrated to measure voltage, current, and temperature. Data logging was performed using embedded systems and validated through digital instrumentation.

## 4. RESULTS AND PERFORMANCE ANALYSIS

The performance of the wireless charging system was evaluated across multiple operating conditions.

### *A. Efficiency Variation with Alignment*

Under perfect alignment, the system achieved a maximum efficiency of approximately 91%. As misalignment increased, efficiency dropped gradually due to reduced magnetic coupling.

**Table 2:** Efficiency vs. Misalignment

| Misalignment (mm) | Efficiency (%) |
|---|---|
| 0 | 91 |
| 20 | 87 |
| 40 | 81 |
| 60 | 74 |
| 80 | 66 |
| 100 | 58 |

The results indicate a nonlinear decline in efficiency, emphasizing the importance of alignment optimization.

*B. Power Transfer Characteristics*

The output power decreased proportionally with misalignment, but the system maintained stable voltage levels, indicating robustness in control mechanisms.

*C. Thermal Performance*

Temperature rise remained within acceptable limits (<15°C), suggesting effective thermal management.

*D. Stability Analysis*

Despite efficiency losses, the system demonstrated stable operation without fluctuations or interruptions, highlighting its reliability.

## 5. DISCUSSION AND DESIGN IMPLICATIONS

The experimental findings provide critical insights into the design and deployment of wireless EV charging systems. The strong dependence of efficiency on coil alignment underscores the need for advanced alignment mechanisms or adaptive control strategies. Techniques such as dynamic coil positioning, magnetic shielding, and multi-coil arrays can enhance tolerance to misalignment (Singh & Verma, 2024).

Another significant observation is the trade-off between air gap and efficiency. While larger gaps improve usability, they reduce coupling efficiency. Therefore, an optimal balance must be achieved through design optimization.

From a system perspective, the integration of smart control units plays a vital role in maintaining stability. Real-time monitoring and feedback mechanisms can mitigate performance degradation by adjusting operating parameters dynamically.

Furthermore, the study highlights the importance of material selection and coil geometry. Litz wire and ferrite cores can reduce losses and improve magnetic flux concentration (Chen et al., 2022).

## CONCLUSION AND FUTURE SCOPE

This study systematically evaluated the operational performance of a contactless EV charging system using inductive power transfer technology. The results confirm that wireless charging is a viable alternative to conventional methods, offering enhanced convenience and safety. However, performance is significantly influenced by alignment and spatial configuration.

The system demonstrated high efficiency under optimal conditions and maintained operational stability under moderate misalignment, indicating its practical applicability. Nevertheless, improvements are required to enhance tolerance to positional variations and to maximize energy transfer efficiency.

Future research should focus on:

- Adaptive alignment technologies
- Advanced resonant compensation techniques
- Integration with smart grid systems
- High-power scalability for commercial EVs

The transition toward wireless charging infrastructure will play a pivotal role in accelerating EV adoption and shaping the future of sustainable transportation.

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