JURNAL EDUNITRO
JURNAL PENDIDIKAN TEKNIK ELEKTRO
HTTPS://EJURNAL.UNIMA.AC.ID/INDEX.PHP/EDUNITRO
E-ISSN 2776-284X
P-ISSN 2776-2920
Vol. 5, No. 1, April 2025

# Capacitive Wireless Charging Technology in Wireless Electric Vehicle Battery Charging: Challenges and Opportunities

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Received: December 15th, **2024.** Revised: February 15th, **2025.** Accepted: February 19th, **2025**
Available online: February 22nd, **2025**. Published: April, **2025**.

**Abstract— This study aims to identify challenges, opportunities, and solutions related to capacitive wireless charging (Capacitive Power Transfer, CPT) technology in electric vehicles (EVs). The background of the study focuses on the need for efficient and environmentally friendly charging technology to support wider EV adoption. The methods include laboratory experiments to test electrode design, charging distance, and environmental conditions on power transfer efficiency. The results show that optimal electrode design and proper spacing and positioning can improve power transfer efficiency. However, temperature and humidity factors also affect system performance. In conclusion, CPT technology has great potential in supporting electric vehicle charging, although challenges still need to be overcome. The implications of this study are the need for further development in system design that is adaptive to environmental conditions and integration with smart grids to improve the efficiency and adoption of this technology.**

**Keywords:** Capacitive wireless charging, capacitive power transfer, electric vehicle, battery charging.



## I. Introduction

Electric vehicles (EVs) are increasingly becoming a primary solution to reduce carbon emissions and dependence on fossil fuels amid the global climate crisis. EVs offer a cleaner and more efficient alternative to traditional fossil fuel-based vehicles. However, the success of EV adoption is highly dependent on the advancement of charging technology, which is one of the main obstacles faced by EV users today (Acharige et al., 2023; Wang et al., 2023).

Conventional EV battery charging using cables requires direct physical interaction between the vehicle and the charging infrastructure (Mamahit et al., 2022). Although this technology is well-established, various issues, such as impracticality, hardware wear and tear, and standard incompatibility, still need to be addressed (Chen et al., 2020). As a solution, wireless charging technology is gaining attention because it offers greater convenience, efficiency, and safety.

One of the promising approaches in wireless charging is capacitive wireless charging technology. This technology utilizes electric fields to transfer energy without direct contact, offering advantages such as more straightforward design, lower manufacturing costs, and compatibility with various vehicle designs (Huang et al., 2022). However, this technology also faces several technical challenges, such as lower power transfer efficiency compared to inductive methods and sensitivity to the distance between the charger and receiver (Mahdi et al., 2023; Erel et al., 2022). The development of Capacitive Power Transfer (CPT) technology for electric vehicle charging has been the subject of significant research in recent years. CPT offers a promising alternative with lighter system weight, lower manufacturing costs, and increased efficiency, especially under misalignment conditions (Gao et al., 2022). This technology uniquely utilizes electric fields for power transfer, making it ideal for applications that require reduced electromagnetic interference compared to Inductive Power Transfer (IPT) methods (Huang et al., 2022; Zhang & Zhao, 2023).

Wireless charging technology for EVs has seen rapid development in the past decade. The inductive coupling method is the most commonly applied approach, in which magnetic fields transfer energy (Park et al., 2018). Various studies have demonstrated the high efficiency of this method, especially for static and dynamic applications. However, this method has limitations regarding production cost, component size, and the influence of electromagnetic fields on the surrounding environment (Kim & Choi, 2021).

On the other hand, capacitive technology has become a growing research area due to its potential to overcome some of the drawbacks of the inductive method. This technology uses a capacitor as the power transfer medium, allowing flexible dielectric materials to be used and reducing magnetic field emissions (Gao et al., 2022). However, this technology has yet to be fully adopted in commercial applications due to challenges such as optimal electrode design, improving power transfer efficiency, and minimizing energy losses (Liu et al., 2023).

Recent studies have shown that CPT can be implemented for static charging and dynamic charging, such as highway systems designed for charging while vehicles are moving (Liu et al., 2023; Singh et al., 2021). However, the implementation of CPT still needs to be improved, such as lower power transfer efficiency compared to IPT and sensitivity to environmental disturbances, such as foreign material interference or humidity changes (Chen et al., 2020; Zhou et al., 2023). Various efforts have been made to improve the performance of capacitive technology, including the development of advanced dielectric materials, adaptive power control algorithms, and integration with intelligent battery management systems (Singh et al., 2021; Wang et al., 2022). However, studies examining this technology's challenges and opportunities in the context of large-scale implementation still need to be completed.

Although capacitive wireless charging technology has been the subject of intensive research, several significant research gaps exist. Most current research focuses on technical aspects, such as circuit design and energy efficiency optimization. In contrast, other aspects, such as system resilience to environmental disturbances, device interoperability, and the impact of implementation costs on the EV market, have yet to be comprehensively studied (Zhou et al., 2023).

Furthermore, most of the available literature discusses the application of this technology at a laboratory scale, so there needs to be more analysis of the fundamental challenges in large-scale implementation in urban or rural environments (Hansen & Johansen, 2020). Further research is needed to understand how this technology can effectively integrate with existing transportation infrastructure.

CPT systems also require the development of efficient resonant networks to maintain the stability of the transferred power under varying conditions (Kim & Choi, 2021). A study by Hansen and Johansen (2020) highlighted the importance of developing innovative dielectric materials to improve the performance of CPT in large-scale applications. In addition, technical evaluations suggest that a hybrid approach, namely a combination of CPT and IPT, could be a long-term solution to optimize charging efficiency under various usage conditions (Park et al., 2018; Wang et al., 2022).

This research offers novelty in several important aspects. First, this research will deeply examine the main challenges faced by capacitive wireless charging technology, including power transfer efficiency, stability under dynamic conditions, and potential environmental disturbances. Second, this research will also explore the opportunities this technology offers to support the widespread adoption of EVs, including integration with IoT and smart grid technologies.

In addition, this research seeks to provide a more holistic approach by combining technical, economic, and environmental analysis, which is rarely found in the current literature. Thus, this research is expected to contribute significantly to the existing literature and support the developing of more practical and sustainable EV charging technology.

Based on the description above, several main questions that are the focus of this research are:

1. What are the technical and practical challenges in implementing capacitive wireless charging technology for EVs?
2. How can the efficiency and performance of this technology be improved to meet the real needs of EV users?
3. What strategic opportunities can be utilized to encourage the adoption of this technology on a global scale?
4. How does implementing this technology impact the sustainable transportation and energy ecosystem?

This research aims to:

1. Identify the main challenges facing capacitive wireless charging technology for EVs.
2. Explore the opportunities of this technology in supporting widespread EV adoption.
3. Provide strategic recommendations for developing and implementing more efficient, affordable, and environmentally friendly capacitive wireless charging technology.

With this contribution, this research is expected to guide technology developers, policymakers, and other stakeholders in supporting the transformation toward more sustainable transportation.

## II. METHOD

This study analyzes the challenges, opportunities, and impacts of implementing capacitive wireless charging (CPT) technology in electric vehicles (EVs). The research approach will consist of two main stages to achieve this goal: a literature study and laboratory experiments followed by data analysis.

### A. *Literature Study*

A literature study will be conducted to identify challenges and opportunities in implementing CPT technology and to understand the current status of research in wireless charging for electric vehicles. The literature used includes international journals, conference articles, and relevant books, focusing on articles published in journals indexed by Scopus, WoS, and DOAJ. The main focus of this literature study is:

- Technological Challenges: Analysis of technical issues such as power transfer efficiency, optimal electrode design, and sensitivity to the distance between the charger and receiver.
- Strategic Opportunities: Identify opportunities that can be utilized to encourage the adoption of this technology globally, both in terms of efficiency, cost, and compatibility with existing infrastructure.
- Technology Development and Innovation: This section provides an overview of the latest technological innovations in CPT, as well as its advantages and disadvantages compared to other charging methods, such as Inductive Power Transfer (IPT).

### B. *Laboratory Experiments*

Laboratory experiments will be conducted to test the performance of CPT technology under various operating conditions. These experiments aim to evaluate the power transfer efficiency and its impact on energy efficiency and electrode design. Testing will cover several variables that affect the performance of the CPT system, such as:

- Electrode Design: The design of electrodes will be explored to find the most efficient configuration for minimizing energy loss. Various electrode shapes will be tested, including the size and material used, to determine their effect on power transfer efficiency.
- Charging Distance and Position: Testing is conducted to determine how the distance and position between the charger and receiver affect power transfer efficiency. Using simulations and practical testing, the extent to which CPT technology is able to transfer power effectively over varying distances will be analyzed.
- System Performance under Various Conditions: The CPT system will be tested under various environmental conditions, such as temperature and humidity variations, to observe the effect of external factors on power transfer performance.

The test uses standard test equipment that has been accepted in the scientific community for CPT technology, as well as measuring instruments that can monitor technical parameters such as voltage, current, and power efficiency. The data obtained from this experiment will be used to compare the performance of CPT technology with other wireless charging technologies, such as IPT.

### C. *Data Analysis*

Data obtained from laboratory experiments will be analyzed using statistical methods and mathematical models to identify factors that most affect the efficiency and performance of CPT technology. The analysis methods used include:

- Regression Analysis: Used to identify relationships between tested variables (e.g., charging distance, electrode design, temperature) and power transfer efficiency.
- Computer Simulation: Simulation models will be used to estimate the performance of the CPT system under a wider and more varied set of conditions and evaluate potential optimizations in system design.
- Comparative Analysis: Data from these experiments will be compared with IPT systems and other charging technologies to assess CPT’s advantages and disadvantages in terms of efficiency and ease of implementation.

Based on the research results, strategic recommendations will be formulated to advance capacitive wireless charging technology development. These recommendations will include suggestions for more efficient electrode designs, improving CPT system performance through technological innovation, and policies that can encourage large-scale adoption of CPT technology in global transportation.

This research method combines literature studies, laboratory experiments, and data analysis to evaluate capacitive wireless charging technology’s technical challenges and opportunities for electric vehicles. It hopes to provide an understanding of how this technology can be optimized and implemented widely to support the transition towards more sustainable transportation.

## III. RESULTS

### A. *Challenges of Capacitive Wireless Charging Technology for EVs*

The main challenges in implementing capacitive wireless charging technology for electric vehicles include power transfer efficiency, optimal electrode design, sensitivity to distance between charger and receiver, and potential energy loss. Laboratory experiments conducted on various electrode designs found that one of the main issues affecting system efficiency is the inability of this technology to maintain high levels of power transfer efficiency over long distances between the charger and receiver.

- Power Transfer Efficiency: Tests have shown that the power transfer efficiency for CPT systems is lower than that of inductive technology (IPT), especially at more considerable distances. This is due to limitations in the electric field that can be produced by the electrodes and their effect on the ability to transmit power efficiently.
- Electrode Design: Suboptimal electrode design also affects power transfer efficiency. Experiments have shown that using better conductive materials and increasing the size of the electrodes can improve efficiency. However, adjustments to electric vehicles' size and comfort requirements are required.
- Distance Sensitivity: The distance between the charger and receiver is a critical factor in the performance of CPT systems. In the tests conducted, the power transfer efficiency decreased significantly when the distance between the two devices exceeded a few centimeters. This is one of the main obstacles in applying this technology for charging electric vehicles in the real world.

The results of these experiments show that although CPT technology has great potential, there are significant challenges in achieving efficiency comparable to other wireless charging technologies, such as IPT. In addition, efficient electrode design and ways to reduce power loss need to be considered when developing this technology.

### *B. Improving the Efficiency and Performance of CPT Technology for EVs*

The efficiency and performance of CPT technology for electric vehicles can be improved through several technical strategies that have been tested in this study. Some steps that are effective in improving the performance of this technology include:

- Use of Better Conductive Materials: Tests involving new conductive materials, such as high-conductivity metals or composite materials, have significantly improved power transfer efficiency. Materials such as copper and aluminum can improve the power flow between the charger and the receiver.
- Improved Electrode Design: Larger and optimally shaped electrode designs (e.g., spiral or circular) can reduce resistance and increase power transfer. Using materials with low friction coefficients also helps reduce power loss due to friction and heat.
- Adjustment of Charging Distance and Position: Experiments have shown that adjusting the charging position and distance can help improve efficiency. Charging systems equipped with sensors to detect the position and automatically adjust the distance show better performance than systems with a fixed distance.
- Optimization of Energy Management System: CPT systems equipped with intelligent power management technology that can adjust the energy flow based on the vehicle's needs also show better efficiency and optimal energy use results.

With these steps, CPT technology can be improved to meet the growing needs of electric vehicles, especially in terms of charging speed and reducing the required charging time.

### *C. Strategic Opportunities in CPT Technology Adoption*

CPT technology offers a tremendous strategic opportunity to support the global adoption of electric vehicles. Some of the opportunities that can be utilized to drive the development and adoption of this technology include:

- Electromagnetic Interference Reduction: One of the main advantages of CPT compared to IPT technology is its ability to reduce electromagnetic interference (EMI). By utilizing electric rather than magnetic fields, CPT offers a safer and more environmentally friendly alternative, especially in sensitive applications such as electric vehicles and medical devices.
- Public Charging Infrastructure Applications: CPT technology allows for easier charging in public areas such as highways or charging stations, as it does not require a physical connecting device. This can accelerate the development of wireless charging infrastructure in large cities and the adoption of electric vehicles.
- Integration with Smart Grid Technology: CPT can be integrated with intelligent grid systems to improve the efficiency of energy distribution by allowing electric vehicles to charge automatically when connected to the grid. This opens up opportunities to reduce dependence on traditional energy sources and support the transition to renewable energy.
- Reduction in Charging Cost and Time: With improved efficiency and more optimized design, CPT technology can reduce the cost and time required to charge electric vehicles. This will improve user convenience and accelerate the transition to the widespread adoption of electric vehicles.

### *D. Impact of CPT Technology Implementation on the Sustainable Transportation and Energy Ecosystem*

The implementation of CPT technology can have a significant positive impact on the sustainable transportation and energy ecosystem. Some of the positive impacts that can be expected include:

- Carbon Emission Reduction: With the broader adoption of electric vehicles, CPT technology can support the reduction of carbon emissions from transportation. Since the transportation sector is a major contributor to global carbon emissions, adopting CPT technology can accelerate the transition to greener mobility.
- Improved Green Charging Infrastructure: CPT technology can reduce the need for more complicated and environmentally unfriendly cable-based charging infrastructure by focusing on efficient wireless charging. This can also reduce the energy waste that occurs in conventional charging systems.
- Energy Savings: Implementing more efficient CPTs can reduce energy waste in the charging process of electric vehicles, thereby reducing the need for additional energy resources. This is critical in reducing dependence on fossil fuels and supporting renewable energy goals.

This study shows that although capacitive wireless charging (CPT) technology has challenges in terms of efficiency and design, there is great potential to overcome these challenges through innovations in materials, electrode design, and power regulation systems. In addition, CPT technology offers strategic opportunities in reducing electromagnetic interference and supporting a more flexible and environmentally friendly charging infrastructure. Its impact on the transportation and sustainable energy ecosystem is significant, as it can reduce carbon emissions, accelerate the transition to renewable energy, and improve energy efficiency. Therefore, further research is needed to optimize this technology for broader adoption and support sustainability in the transportation sector.

### *E. Laboratory Experiment Test Results*

The following are the results of laboratory experiment tests related to electrode design, charging distance and position, and the performance of the capacitive wireless charging (CPT) system under various conditions. The data presented in the following table includes several variables tested to assess the efficiency and performance of the system.

1. Electrode Design Test Results

Table 1 compares power transfer efficiency based on variations in electrode design (size and material).

**Table 1**. Comparison of power transfer efficiency based on electrode design variations

| Electrode Design | Material | Electrode Size ($cm^2$) | Power Transfer Efficiency (%) |
|---|---|---|---|
| Design A | Copper | 10 | 85 |
| Design B | Aluminum | 15 | 88 |
| Design C | Copper | 20 | 92 |
| Design D | Alloy | 25 | 94 |

Larger electrode designs (Designs C and D) show improved power transfer efficiency, with Design D using a more efficient alloy material. Increasing electrode size improves power transfer efficiency, although a more significant size can affect the overall system size, which must be considered in practical applications.

2. Charging Distance and Position Test Results

Table 2 shows the relationship between charging distance and power transfer efficiency at various charging positions.

Table 2. The relationship between charging distance and power transfer efficiency

| Distance (cm) | Charging Position | Power Transfer Efficiency (%) |
|---|---|---|
| 2 | Vertical | 92 |
| 5 | Vertical | 85 |
| 5 | Horizontal | 87 |
| 10 | Vertical | 75 |
| 10 | Horizontal | 72 |

Shorter charging distances (2 cm) provide the highest power transfer efficiency, especially in vertical positions. Efficiency drops significantly when the distance exceeds 5 cm, especially in horizontal positions, indicating the importance of proper placement to maximize power transfer.

3. Performance Test Results under Various Conditions

Table 3 shows the power transfer efficiency under various environmental conditions, including variations in temperature and humidity.

**Table 3**. Power transfer efficiency under various environmental conditions

| Environmental Conditions | Temperature (°C) | Humidity (%) | Power Transfer Efficiency (%) |
|---|---|---|---|
| Condition A | 20 | 40 | 90 |

| Environmental Conditions | Temperature (°C) | Humidity (%) | Power Transfer Efficiency (%) |
|---|---|---|---|
| Condition B | 30 | 50 | 85 |
| Condition C | 40 | 60 | 80 |
| Condition D | 20 | 80 | 92 |

The power transfer efficiency tends to decrease with increasing temperature and humidity. Conditions with higher temperatures and higher humidity (Condition C) show a significant decrease in efficiency, which may indicate the effect of temperature on the conductivity of the electrode material and the power transfer process.

Larger electrode designs and materials with higher conductivity improve power transfer efficiency. Charging distance and position significantly affect power transfer efficiency, with vertical charging at short distances providing the best results. Environmental conditions such as temperature and humidity significantly impact the performance of CPT systems and need to be considered in the development of this technology. Improvements in electrode design and the arrangement of charging distance and position will be important factors in optimizing the performance of capacitive wireless charging systems for electric vehicles.

### *F. Data Analysis Results*

Based on the test results, here is an in-depth analysis of the data obtained from the experiments.

1. Analysis of Power Transfer Efficiency in Electrode Design

The data in Table 1 show that larger electrode designs made of conductive materials with high conductivity coefficients, such as copper and alloys, provide better efficiency. Designs C and D, although larger, show significant efficiency improvements (92% and 94%, respectively). This indicates that electrode design has a direct effect on power transfer efficiency.

However, it should be noted that increasing the electrode size also has the potential to increase the overall cost and size of the system. Therefore, when choosing an electrode design, one must consider the balance between efficiency and system size, especially in electric vehicle applications prioritizing space efficiency.

2. Analysis of the Effect of Charging Distance and Position

Table 2 shows that the charging distance is an important factor affecting the efficiency of the CPT system. Power transfer efficiency decreases significantly as the distance between the charger and receiver increases. At a distance of 10 cm, the power transfer efficiency drops sharply, both in vertical and horizontal positions, indicating that CPT wireless charging is highly dependent on the proximity between the charger and receiver.

The vertical position at a short distance (2 cm) produced the best efficiency, with a value of 92%. This indicates that the orientation of the system also significantly impacts charging efficiency. The horizontal position, which tends to be more challenging to maintain at a fixed distance, has a slightly lower efficiency at the same distance. Therefore, position and distance settings must be considered when designing a wireless charging system for electric vehicles to achieve maximum efficiency.

3. Effect of Environmental Conditions on System Performance

From Table 3, it can be concluded that the ambient temperature and humidity significantly affect the system efficiency. At a temperature of 40°C and a humidity of 60%, the power transfer efficiency drops to 80%, indicating that increasing temperature and humidity can reduce the power transfer efficiency.

Conditions with lower temperatures and humidity (Condition A) provide the highest efficiency at 90%. This suggests that in real-world applications, environmental conditions, such as hotter or more humid charging locations, must be considered when designing CPT systems to ensure optimal performance.

The data analysis shows that larger electrode designs and better conductive materials improve power transfer efficiency. However, CPT systems are highly affected by charging distance and position, with shorter distances and vertical positions providing higher efficiencies. In addition, environmental conditions, such as temperature and humidity, can affect system performance, highlighting the importance of setting operating conditions to maximize power transfer efficiency.

## IV. DISCUSSIONS

### *A. Electrode Design and Power Transfer Efficiency*

The test results show that larger electrode designs and the use of better conductive materials, such as copper and alloys, can improve power transfer efficiency. This finding is in line with previous studies showing that selecting the right electrode material significantly improves the efficiency of wireless charging systems. For example, Zhang and Zhao (2023) stated that better conductive materials, such as copper and aluminum, can minimize energy losses during power transfer.

A study by Wang and Lee (2021) also confirmed the importance of optimal electrode design to improve the efficiency of wireless charging systems. They showed that the size and shape of the electrode, such as a spiral design, can affect the quality of power transfer. Larger electrode designs tend to increase the contact area, which reduces resistance and improves power transfer efficiency (Zeng et al., 2019). Therefore, further research on more efficient electrode designs is essential to achieve optimal performance in electric vehicle applications.

However, in a study conducted by Huang et al. (2022), although larger electrode designs provide higher efficiency, considerations related to system size and complexity must be taken into account. Increasing electrode size can increase the cost and size of the device, which may be better in electric vehicle applications where space efficiency is important (Khan et al., 2023).

### B. *Effect of Distance and Charging Position*

The experimental results show that the distance between the charger and receiver significantly affects the power transfer efficiency. The efficiency decreases when the distance exceeds 5 cm, and this decrease is more drastic in the horizontal position. This confirms previous findings by Liu et al. (2023), who noted that capacitive wireless charging technology is susceptible to changes in the distance between the power source and the receiver. This is also supported by research by Huang et al. (2022), who showed that charging at a longer distance reduces the strength of the electric field used to transfer power.

Wang and Lee (2021) in their study showed that the efficiency of wireless power transfer can be significantly affected by the charging position. The vertical position at short distances gives better results because the electric field is more concentrated and more straightforward to transfer. They also added that proper positioning is important to maintain high efficiency in wireless charging technology. Therefore, a system design that dynamically considers distance and position could be a solution to improve efficiency. Further research by Zhang and Zhao (2023) also showed that CPT technology can be optimized by using a charging system that automatically adjusts the charging position and distance, allowing for higher power transfer efficiency under various conditions.

### C. *Effect of Environmental Conditions on Performance*

The test results show that temperature and humidity affect the power transfer efficiency in the CPT system. As temperature and humidity increase, the efficiency decreases. This is consistent with previous findings showing that environmental factors can affect the performance of wireless charging technology. For example, Liu et al. (2023) found that higher temperatures can decrease the conductivity of electrode materials, leading to decreased power transfer efficiency.

In addition, Zhang and Zhao (2023) revealed that changes in humidity can also change the dielectric properties of insulating materials, which affects the efficiency of the electric field used for power transfer. Their research suggests that wireless charging systems should consider environmental factors to ensure stable performance under various conditions.

Huang et al. (2022) also noted that temperature and humidity affect wireless charging performance, especially in CPT systems that rely on electric fields. They suggested the development of materials that are more resistant to temperature and humidity fluctuations to reduce these negative impacts on system efficiency. In this context, the use of composite materials that are resistant to temperature and humidity changes could be a solution to improve the performance of wireless charging systems under varying environmental conditions.

Research by Wang and Lee (2021) confirmed that the influence of temperature and humidity is very significant in wireless charging. Therefore, a wireless charging system that can adapt to changing environmental conditions is needed to maintain optimal performance, especially in electric vehicle applications that operate in various climate conditions.

### D. *Implications for CPT Technology Development and Adoption*

Overall, the findings from this experiment provide a clear picture of the challenges facing CPT technology and the opportunities for its development. These results suggest that despite the many factors that affect power transfer efficiency, CPT technology has great potential to support the broader adoption of electric vehicles if these challenges can be overcome.

Further research by Liu et al. (2023) suggests that with improved electrode design and optimization of charging distance and position, CPT technology can be an efficient and environmentally friendly alternative for electric vehicle charging. Furthermore, research by Zhang and Zhao (2023) suggests that power transfer efficiency can be significantly improved with a dynamic charging system that can automatically adjust the distance and position.

Strategic opportunities to drive the adoption of this technology include the development of more efficient materials that are resistant to temperature and humidity changes and more flexible charging system designs. Research by Huang et al. (2022) suggests that integrating CPT technology with innovative grid systems can improve energy distribution efficiency and support the adoption of electric vehicles on a global scale.

In addition, environmental factors such as temperature and humidity significantly affect the performance of the CPT system, which was also revealed in a study by Lee et al. (2023), which found that high temperatures reduce the quality of power transfer due to increased resistance in conductive and insulating materials. This suggests that wireless charging systems should consider these factors to ensure stable performance under varying conditions. Research by Zhang et al. (2022) also supports these findings, emphasizing the importance of designs that can compensate for temperature and humidity fluctuations to maintain system efficiency.

In the future, the development of CPT technology should focus on optimizing materials more resistant to extreme conditions. Materials such as carbon composites or conductive polymers, as proposed by Lee et al. (2023), could be a solution to overcome temperature and humidity problems. Systems equipped with temperature and humidity sensors can also be integrated to automatically adjust charging parameters, which will reduce the impact of environmental conditions on power transfer efficiency (Wang & Zhang, 2021).

In this case, adapting technology with smart grid integration and IoT technology can also improve energy distribution management and charging efficiency, as explained by Smith et al. (2022), who suggested utilizing network connectivity to monitor and regulate the charging process in real time.

Despite challenges in power transfer efficiency, electrode design, and environmental conditions, CPT technology shows great potential to support the widespread adoption of electric vehicles. Optimization of electrode design, charging distance, and dynamic positioning can improve the efficiency of this technology. Therefore, developing this technology by considering these factors is very important to ensure the successful implementation of CPT in electric vehicle charging systems.

## V. CONCLUSION

This study identified several key technical challenges in implementing CPT for EVs, including lower power transfer efficiency compared to inductive methods, sensitivity to charging distance, and dependence on electrode design and materials used. Further development is needed to optimize electrode design, improve system efficiency, and reduce energy losses.

The test results show that larger electrode designs and better conductive materials can improve power transfer efficiency. The effect of charging distance and position is also significant, with shorter distances and vertical positions providing higher efficiencies. However, the system is still affected by environmental factors, such as temperature and humidity, which can degrade performance. This shows that while CPT technology has excellent potential, improving efficiency and adapting to environmental conditions is essential.

If the technical challenges can be overcome, CPT technology has great potential to support the broader adoption of electric vehicles. Charging systems that automatically adjust distance and position, use materials more resistant to temperature and humidity fluctuations, and integrate with smart grids can significantly improve performance and efficiency. Further development of this technology can also support the renewable energy ecosystem by reducing dependence on cable-based charging systems.

CPT technology can positively impact the transportation ecosystem, especially in increasing the convenience and efficiency of electric vehicle charging. In addition, adopting this technology can contribute to developing sustainable energy infrastructure by reducing the use of fossil fuels and increasing energy efficiency.

Based on these findings, further research is needed in several areas. Material Development and Electrode Design: Higher conductivity materials and more efficient electrode designs must be further explored to improve power transfer efficiency, especially over longer distances. Adaptability to Environmental Conditions: CPT systems need to be equipped with adaptive technology that can adjust charging efficiency with changes in temperature and humidity. Integration with Smart Grid Technologies: Research examining the integration of CPT with smart grids and IoT systems to optimize energy distribution and EV charging would be beneficial. Large-Scale Trials: Further testing on a larger scale with real EVs to assess the performance and durability of the system under various field conditions. By focusing on these areas, CPT technology can develop into an efficient and practical charging solution for EVs in the future.

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