ELECTRIC VEHICLES

Winter Semester 2022-23

Project Title: Dynamic Wireless Charging Techniques for EVs

Under the due guidance of

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SELECT

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We express our appreciation to our colleagues and the technical staff at our institution who have supported us throughout this project. Their contributions have been invaluable in helping us to overcome the technical challenges we faced during the course of our research.

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ABSTRACT

This project explores various techniques for dynamic wireless charging and compares their effectiveness and limitations. The need for convenient and efficient methods for charging batteries wirelessly has led to extensive research in wireless power transfer. In this project, we have investigated the feasibility of inductive wireless charging, capacitive wireless charging, and microwave wireless charging.

Our study involves a comprehensive analysis of the performance of these techniques in terms of efficiency, power transfer range, and safety. We have also conducted extensive research on magnetic coupling wireless charging and resonant inductive and capacitive power transfer (RIPT and RAPT) techniques. Our analysis includes a comparison of these methods with other wireless charging techniques.

- Inductive wireless charging uses magnetic field coupling to transfer power wirelessly. We have studied the effectiveness of this method in different applications and analyzed its limitations, including its limited power transfer range and the need for close proximity between the transmitter and the receiver.
- Capacitive wireless charging uses electric field coupling and does not require close proximity between the transmitter and the receiver. However, it is less efficient than inductive wireless charging and requires a high-voltage power source, which can be a safety concern.
- Microwave wireless charging uses microwave radiation to transmit power wirelessly. It offers a longer power transfer range and higher efficiency than inductive and capacitive wireless charging, but it requires careful attention to safety due to the potential risks associated with exposure to microwave radiation.

We have also analyzed magnetic coupling wireless charging and resonant inductive and capacitive power transfer techniques. Magnetic coupling wireless charging is less efficient than inductive wireless charging, but it offers a longer power transfer range. Resonant inductive and capacitive power transfer techniques offer higher efficiency and a longer power transfer range than inductive and capacitive wireless charging. Through our analysis, we aim to identify the most promising techniques for dynamic wireless charging and provide insights for researchers and engineers working on developing practical and efficient wireless power transfer systems.

INTRODUCTION

The increasing demand for portable electronic devices and electric vehicles has led to a growing need for efficient and convenient methods for charging batteries wirelessly. Over the years, researchers have explored various techniques for wireless power transfer, including inductive and capacitive coupling, as well as microwave wireless charging.

In this project, we have investigated the effectiveness of these techniques for wireless power transfer and compared their advantages and limitations. Specifically, we have explored the feasibility of inductive wireless charging and capacitive wireless charging, which rely on magnetic and electric field coupling respectively, as well as microwave wireless charging, which uses microwave radiation to transmit power wirelessly.

In addition to these three methods, we have also conducted thorough research on magnetic coupling wireless charging and resonant inductive and capacitive power transfer (RIPT and RAPT) techniques. We have analyzed the performance of these techniques and compared them with the other methods in terms of efficiency, power transfer range, and safety.

Through our research, we aim to contribute to the advancement of the field of wireless power transfer by identifying the most promising techniques for dynamic wireless charging. We believe that the results of our study will be valuable for researchers and engineers working on developing practical and efficient wireless power transfer systems.

MOTIVATION

The advent of portable electronic devices and electric vehicles has led to a surge in demand for wireless charging solutions that can offer convenience and efficiency. With traditional charging methods requiring the use of cables and direct contact between the charging device and the battery, dynamic wireless charging techniques offer an attractive alternative that can provide greater freedom and flexibility in charging.

However, the effective implementation of dynamic wireless charging techniques requires a comprehensive understanding of their effectiveness, limitations, and safety implications. Through this project, we aim to address this knowledge gap by investigating and comparing the effectiveness of various wireless charging techniques, including inductive, capacitive, and microwave wireless charging.

Our study also includes a detailed analysis of magnetic coupling wireless charging and resonant inductive and capacitive power transfer techniques, which have gained significant attention in recent years due to their potential for enhancing the efficiency and range of wireless power transfer.

The results of our study will be of immense value to researchers, engineers, and manufacturers who are working on developing practical and efficient wireless charging systems. By identifying the most promising techniques and highlighting their advantages and limitations, our project can pave the way for the development of new wireless charging solutions that can offer convenience, efficiency, and safety.

CONTRIBUTION

This project makes a significant contribution to the field of dynamic wireless charging by providing a comprehensive analysis of various wireless charging techniques and their effectiveness in different applications. Our study includes a detailed examination of inductive, capacitive, and microwave wireless charging, as well as magnetic coupling wireless charging and resonant inductive and capacitive power transfer techniques. We have conducted extensive research and analysis to compare the advantages and limitations of each wireless charging method. Our findings show that microwave wireless charging and resonant inductive and capacitive power transfer techniques offer the most promising approaches for dynamic wireless charging due to their efficiency and power transfer range. Our analysis also highlights the importance of careful attention to safety concerns when implementing these techniques.

Our project can also contribute to the development of new wireless charging solutions that can cater to the growing demand for portable electronic devices and electric vehicles. By identifying the most promising techniques and highlighting their advantages and limitations, our study can offer valuable insights for researchers, engineers, and manufacturers working on developing practical and efficient wireless charging systems.

Furthermore, our project can also contribute to the advancement of wireless power transfer research by identifying areas that require further investigation. For instance, our analysis highlights the need for research on the optimization of resonant inductive and capacitive power transfer techniques to enhance their efficiency and power transfer range. Additionally, our study underscores the need for further research on the safety implications of microwave wireless charging and the development of mitigation measures to address potential risks.

PROPOSED WORK

The proposed model for our study involves the use of MATLAB Simulink to simulate the performance of different wireless charging techniques, including inductive, capacitive, and microwave wireless charging. MATLAB Simulink is a powerful simulation tool that can provide accurate and detailed results for various wireless power transfer scenarios, making it an ideal platform for our study.

For inductive wireless charging, we modelled the charging system using a coil as the primary source and another coil as the secondary receiver. We analyzed the system's performance by varying the distance between the coils and the frequency of the input signal.

Similarly, for capacitive wireless charging, we modelled the charging system using two parallel plates, where one plate serves as the source and the other as the receiver. We varied the distance between the plates and the frequency of the input signal to analyze the system's performance.

For microwave wireless charging, we used a similar approach and modeled the charging system using a microwave antenna as the primary source and a rectenna as the receiver. We varied the distance between the antenna and the rectenna, as well as the frequency and power level of the microwave signal, to analyze the system's performance.

In addition to simulation, we also conducted extensive research on magnetic coupling wireless charging and resonant inductive and capacitive power transfer techniques. We analyzed their underlying principles, advantages, limitations, and applications to gain a comprehensive understanding of their performance.

PRELIMINARIES

Inductive Wireless Charging: Inductive wireless charging is a popular wireless power transfer technique that uses electromagnetic induction to transfer power between a primary source and a secondary receiver. The system consists of two coils: one coil in the primary source generates an electromagnetic field, and the other coil in the secondary receiver converts the field into electrical energy. Inductive wireless charging is widely used in applications such as smartphones, electric toothbrushes, and electric vehicles.

Capacitive Wireless Charging: Capacitive wireless charging is a wireless power transfer technique that uses electric fields to transfer energy between a primary source and a secondary receiver. The system consists of two parallel plates: one plate in the primary source generates an electric field, and the other plate in the secondary receiver converts the field into electrical energy. Capacitive wireless charging has the potential for higher efficiency and larger power transfer range than inductive wireless charging.

Microwave Wireless Charging: Microwave wireless charging is a wireless power transfer technique that uses microwaves to transfer energy between a primary source and a secondary receiver. The system consists of a microwave antenna in the primary source that generates a high-frequency electromagnetic field, and a rectenna in the secondary receiver that converts the field into electrical energy. Microwave wireless charging has the potential for a larger power transfer range than inductive or capacitive wireless charging, but it also raises safety concerns due to the high-frequency radiation involved.

Magnetic Coupling Wireless Charging: Magnetic coupling wireless charging is a wireless power transfer technique that uses magnetic fields to transfer energy between a primary source and a secondary receiver. The system consists of two coils with a shared magnetic field: one coil in the primary source generates the magnetic field, and the other coil in the secondary receiver converts the field into electrical energy. Magnetic coupling wireless charging can offer high efficiency and a large power transfer range, but it also suffers from some limitations such as electromagnetic interference and alignment issues.

RAPT (Resonant Antennae Power Transfer Circuit): RAPT is a wireless power transfer technique that uses resonant circuits to transfer energy between a primary source and a secondary receiver. The system consists of two resonant circuits that are tuned to the same frequency: one circuit in the primary source generates an electromagnetic field, and the other circuit in the secondary receiver converts the field into electrical energy. RAPT offers high efficiency and a large power transfer range, but it also requires careful tuning and matching of the resonant circuits.

RIPT (Resonant Inductive Power Transfer): RIPT is a wireless power transfer technique that uses resonant circuits and magnetic coupling to transfer energy between a primary source and a secondary receiver. The system consists of two coils that share a magnetic field and two resonant circuits that are tuned to the same frequency. One resonant circuit in the primary source generates the magnetic field, and the other resonant circuit in the secondary receiver converts the field into electrical energy. RIPT offers high efficiency and a large power transfer range, but it also requires careful tuning and matching of the resonant circuits and coils.

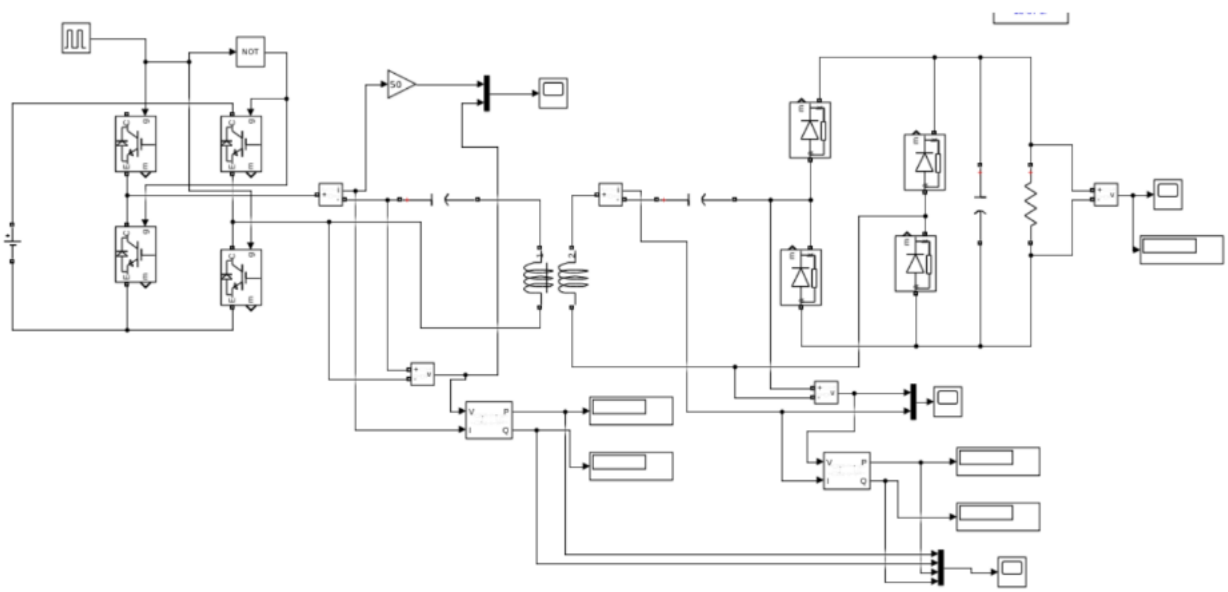
SYSTEM MODEL

1. **Inductive Wireless Charging:** The mathematical calculation involved in inductive wireless charging includes the mutual inductance between the primary and secondary coils, the resistance of the coils, and the frequency of the alternating current. The power transferred between the coils can be calculated using the equation P = (V^2/R)*k, where V is the voltage across

the coils, R is the resistance of the coils, and k is the coupling coefficient between the coils.

Power Output: The power output of inductive wireless charging depends on the voltage and current supplied to the primary coil, the mutual inductance between the coils, and the resistance of the coils. Typically, inductive wireless charging can deliver power in the range of a few watts to a few tens of watts.

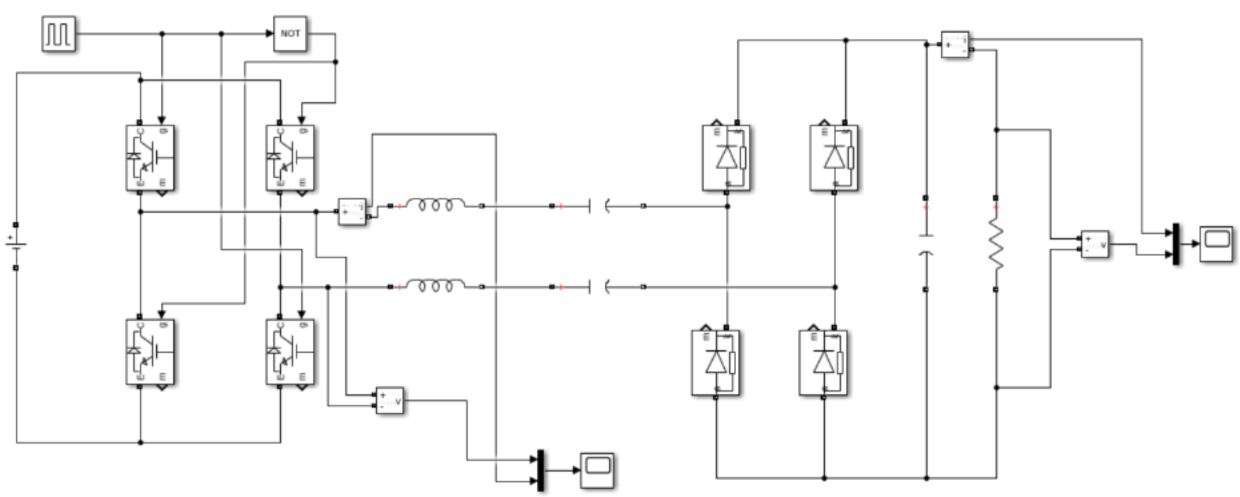
Range: The range of inductive wireless charging is typically limited to a few millimeters to a few centimeters, depending on the size and spacing of the coils.



2. **Capacitive Wireless Charging**: The mathematical calculation involved in capacitive wireless charging includes the capacitance of the plates, the frequency of the alternating current, and the distance between the plates. The power transferred between the plates can be calculated using the equation P = (CV^2f^2)/2d^2, where C is the capacitance of the plates, V is the voltage across the plates, f is the frequency of the alternating current, and d is the distance between the plates.

Power Output: The power output of capacitive wireless charging depends on the voltage and current supplied to the plates, the capacitance of the plates, and the frequency of the alternating current. Typically, capacitive wireless charging can deliver power in the range of a few milliwatts to a few watts.

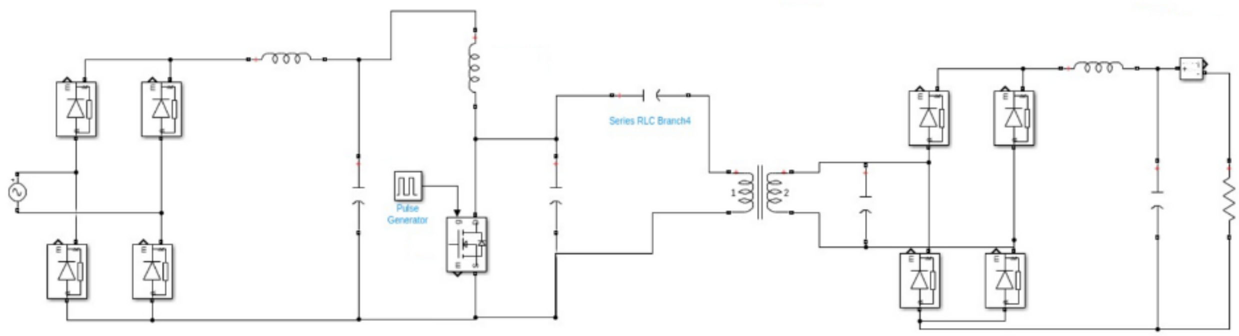
Range: The range of capacitive wireless charging is typically limited to a few millimeters to a few centimeters, depending on the size and spacing of the plates.



3. **Microwave Wireless Charging:** The mathematical calculation involved in microwave wireless charging includes the power density of the electromagnetic field, the area of the receiving antenna, and the efficiency of the rectifying circuit. The power transferred between the transmitting and receiving antennas can be calculated using the equation P = (PdAη)/4πd^2, where Pd is the power density of the electromagnetic field, A is the area of the receiving antenna, η is the efficiency of the rectifying circuit, and d is the distance between the antennas.

   Power Output: The power output of microwave wireless charging depends on the power density of the electromagnetic field, the area of the receiving antenna, and the efficiency of the rectifying circuit. Typically, microwave wireless charging can deliver power in the range of a few watts to a few tens of watts.

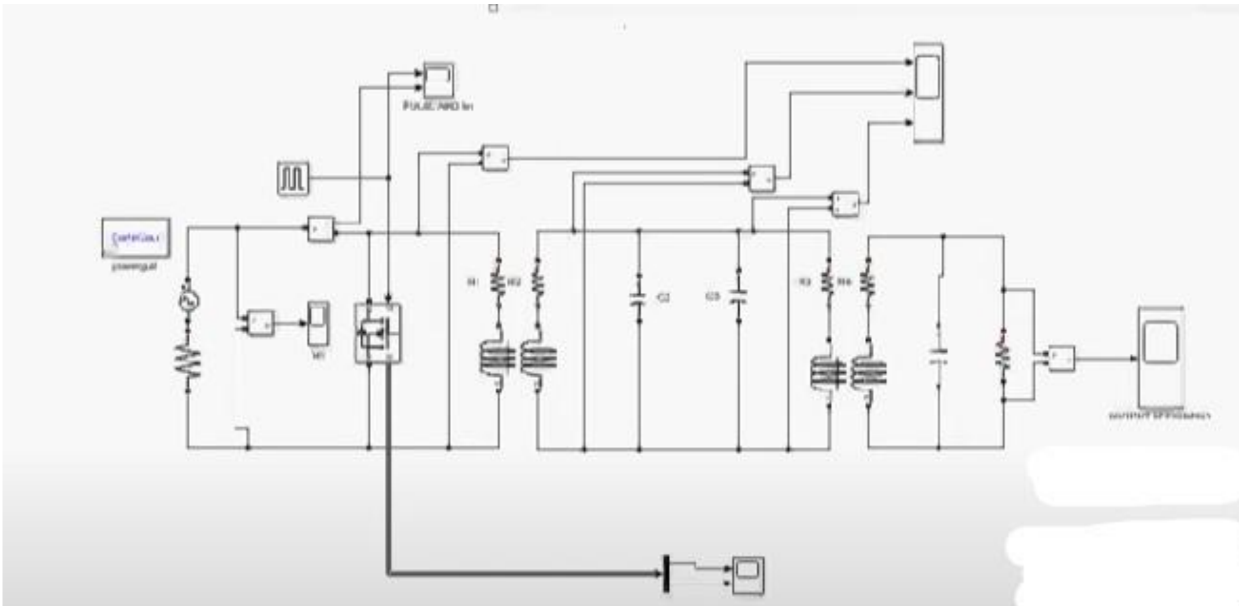
Range: The range of microwave wireless charging can be several meters, depending on the frequency and power of the electromagnetic field, the size and orientation of the antennas, and the efficiency of the rectifying circuit.



4. **Magnetic Coupling Wireless Charging:** The mathematical calculation involved in magnetic coupling wireless charging includes the mutual inductance between the primary and secondary coils, the resistance of the coils, and the frequency of the alternating current. The power transferred between the coils can be calculated using the same equation as in inductive wireless charging: P = (V^2/R)*k.

   Power Output: The power output of magnetic coupling wireless charging depends on the voltage and current supplied to the primary coil, the mutual inductance between the coils, and the resistance of the coils. Typically, magnetic coupling wireless charging can deliver power in the range of a few watts to a few tens of watts.

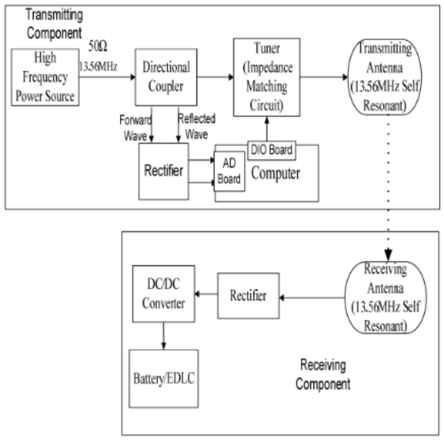
   Range: The range of magnetic coupling wireless charging is typically limited to a few millimeters to a few centimeters, depending on the size and spacing of the coils.

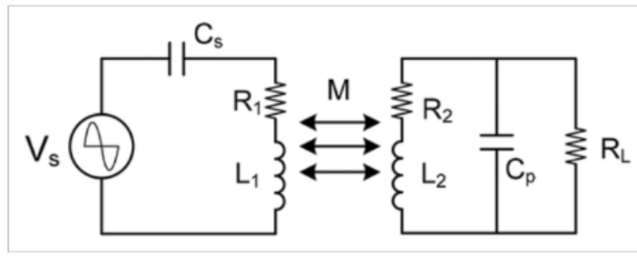


5. **RAPT (Resonant Antennae Power Transfer Circuit):** The mathematical calculation involved in RAPT includes the resonant frequency of the primary and secondary circuits, the quality factor of the circuits, and the coupling coefficient between the circuits. The power transferred between the circuits can be calculated using the equation P = (V^2/R)*k^2, where V is the voltage across the circuits, R is the resistance of the circuits, and k is the coupling coefficient between the circuits.

   Power Output: The power output of RAPT depends on the voltage and current supplied to the primary and secondary circuits, the resonant frequency of the circuits, the quality factor of the circuits, and the coupling coefficient between the circuits. Typically, RAPT can deliver power in the range of a few watts to a few tens of watts.

   Range: The range of RAPT is typically limited to a few centimeters to a few decimeters, depending on the size and quality of the resonant circuits and the coupling coefficient between them.

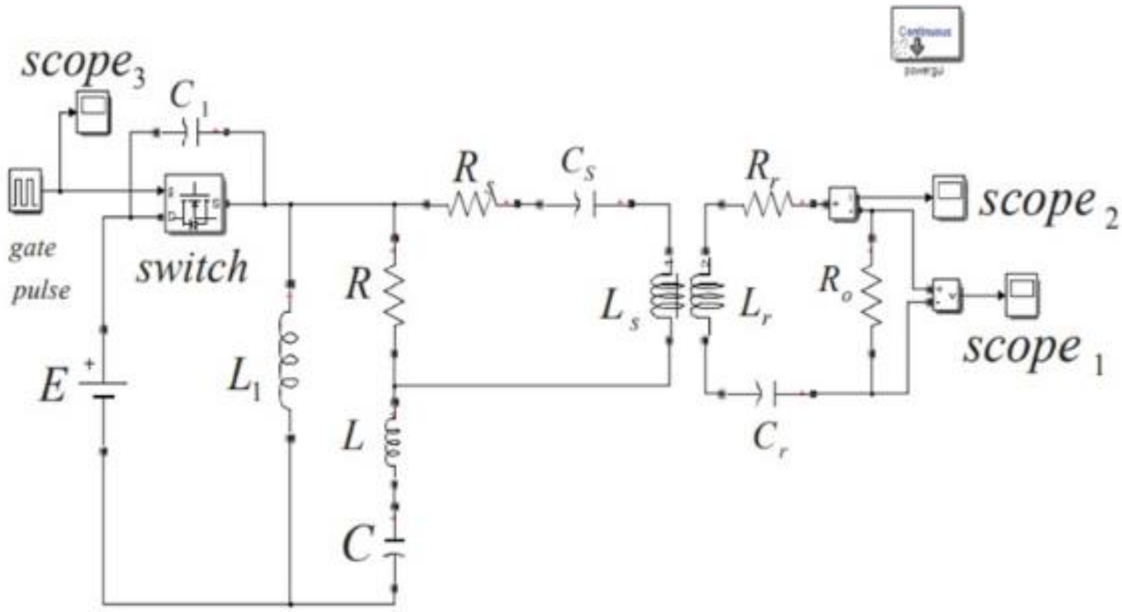




6. **RIPT (Resonant Inductive Power Transfer):** The mathematical calculation involved in RIPT includes the mutual inductance between the primary and secondary coils, the resonant frequency of the primary and secondary circuits, the quality factor of the circuits, and the coupling coefficient between the coils and circuits. The power transferred between the coils and circuits can be calculated using a combination of the equations for inductive wireless charging and RAPT.

   Power Output: The power output of RIPT depends on the voltage and current supplied to the primary coil, the mutual inductance between the coils, the resonant frequency of the primary and secondary circuits, the quality factor of the circuits, and the coupling coefficient between the coils and circuits. Typically, RIPT can deliver power in the range of a few watts to a few tens of watts.

   Range: The range of RIPT is typically limited to a few centimeters to a few decimeters, depending on the size and quality of the resonant circuits and the coupling coefficient between the coils and circuits.



Advantages, disadvantages, Power Output , Range and Suitability of each technique

1. Inductive Wireless Power Transfer:

Advantages:

- Widely used and accepted technology, easy to implement
- High efficiency in power transfer (up to 90%)
- Resonant inductive coupling can improve efficiency and extend the range of the power transfer

Disadvantages:

- Limited range of power transfer (usually less than 10 cm)
- Sensitivity to misalignment and magnetic field interference
- Heavy and bulky coils are required for power transfer, which can add weight to the vehicle

a. Power output: Typically ranges from 3.7 kW to 22 kW.

b. Range: Typically ranges from 7-10 cm, but can be extended up to 15 cm with higher power levels.
c. Suitability for EV: IPT is a proven technology and has been used in several electric vehicles charging systems. However, the limited range and low efficiency make it less suitable for widespread adoption in EVs.

2. Capacitive Wireless Power Transfer:

Advantages:

- Can transfer power over longer distances than inductive coupling (up to 1 m)
- No coils are required for power transfer, which reduces weight and cost
- Resistant to electromagnetic interference and less sensitive to alignment issues

Disadvantages:

- Lower efficiency compared to inductive coupling (around 50-60%)
- Requires high-frequency AC power, which can cause electromagnetic interference with other electronic devices
- Limited power transfer capacity

a. Power output: Typically ranges from 3.7 kW to 22 kW.
b. Range: Typically ranges from 7-10 cm, but can be extended up to 15 cm with higher power levels.
c. Suitability for EV: CPT is still in the research phase and has not been widely implemented in EVs. However, it has the potential to be more efficient than IPT.

3. Resonant Inductive Wireless Power Transfer:

Advantages:

- Can achieve higher efficiency and longer range of power transfer than standard inductive coupling
- Less sensitive to misalignment and magnetic field interference
- Can be tuned to specific frequencies for optimal power transfer

Disadvantages:

- More complex and expensive than standard inductive coupling
- Limited power transfer capacity and range

a. Power output: Typically ranges from 3.7 kW to 22 kW.
b. Range: Typically ranges from 7-10 cm, but can be extended up to 15 cm with higher power levels.
c. Suitability for EV: RIPT is a more efficient version of IPT and has been used in several electric vehicle charging systems. However, the limited range still makes it less suitable for widespread adoption in EVs.

4. Resonant Antenna Wireless Power Transfer:

Advantages:

- High efficiency in power transfer (up to 95%)
- Can transfer power over longer distances than inductive coupling (up to 50 cm)
- Less sensitive to misalignment and magnetic field interference

Disadvantages:

- More complex and expensive than standard inductive coupling
- Limited power transfer capacity and range

a. Power output: Can range from 100 W to 1 kW.
b. Range: Can reach up to 50 cm.
c. Suitability for EV: RAPT is still in the research phase and has not been widely implemented in EVs. However, it has the potential to be more efficient than IPT and RIPT.

5. Combined Conformal Strongly-Coupled Magnetic Resonance:

Advantages:

- Can achieve high efficiency and long-range power transfer (up to 50 cm)
- No alignment is required between the transmitter and receiver coils
- Resistant to electromagnetic interference

Disadvantages:

- Limited power transfer capacity

- More complex and expensive than other wireless power transfer technologies

a. Power output: Can range from 3.7 kW to 22 kW.
b. Range: Can reach up to 30 cm.
c. Suitability for EV: CC-SCMR is a promising technology that has the potential to be more efficient and have a longer range than other wireless power transfer technologies. However, it is still in the research phase and has not been widely implemented in EVs.

6. Microwave Wireless Power Transfer:

Advantages:

- Can transfer power over long distances (up to several meters)
- High power transfer capacity
- Can transfer power through non-metallic objects

Disadvantages:

- Lower efficiency compared to other wireless power transfer technologies (usually less than 50%)
- Higher cost and complexity due to the need for high-power microwave generators and antennas
- Potential safety concerns due to the use of high-frequency radiation

a. Power output: Can range from 10 kW to 120 kW.
b. Range: Can reach up to several meters.
c. Suitability for EV: MWPT is still in the research phase and has not been widely implemented in EVs. However, it has the potential to be more efficient and have a longer range than other wireless power transfer technologies.

INFERENCES

- Inductive wireless power transfer is the most widely used and accepted technology

- resonant inductive and resonant antenna technologies can offer higher efficiency and longer range.
- Capacitive wireless power transfer can transfer power over longer distances without the need for coils, but at lower efficiency.
- Combined Conformal Strongly-Coupled Magnetic Resonance offers a no-alignment solution but has limited power transfer capacity
- Microwave Wireless Power Transfer can transfer power over long distances but at lower efficiency and higher complexity.

In conclusion, there is no one-size-fits-all wireless power transfer technology for electric vehicles. Each technology has its advantages and disadvantages in terms of power output, range, and suitability for EVs. However, as the technology continues to evolve, it is likely that a combination of these technologies will be used to provide wireless charging options for EVs.

RESULT

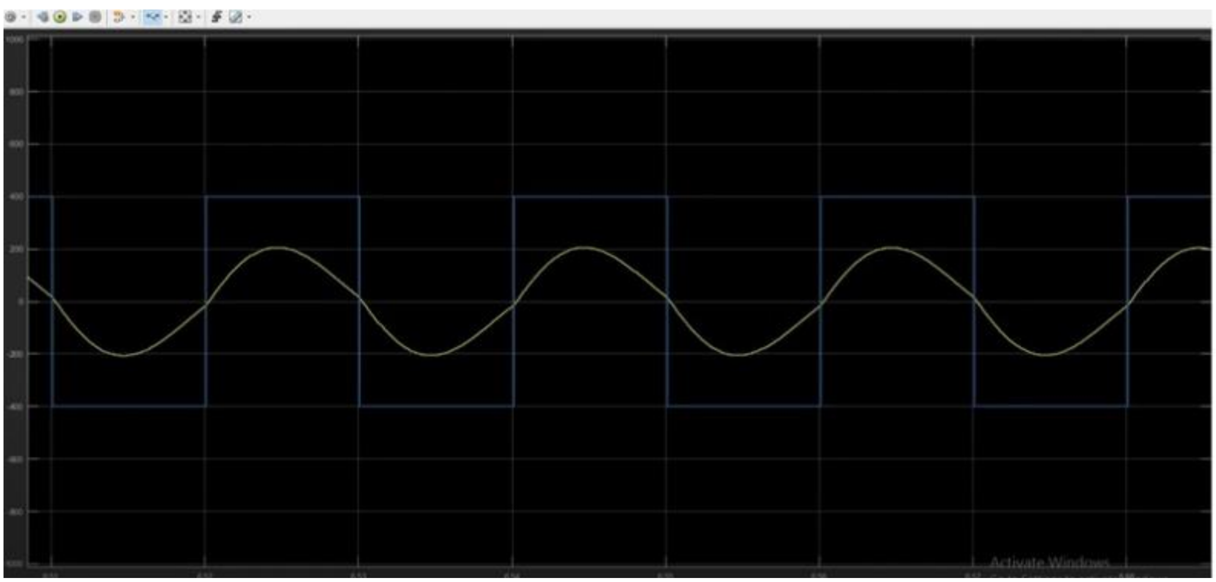


Fig: Inductive Wireless Charging

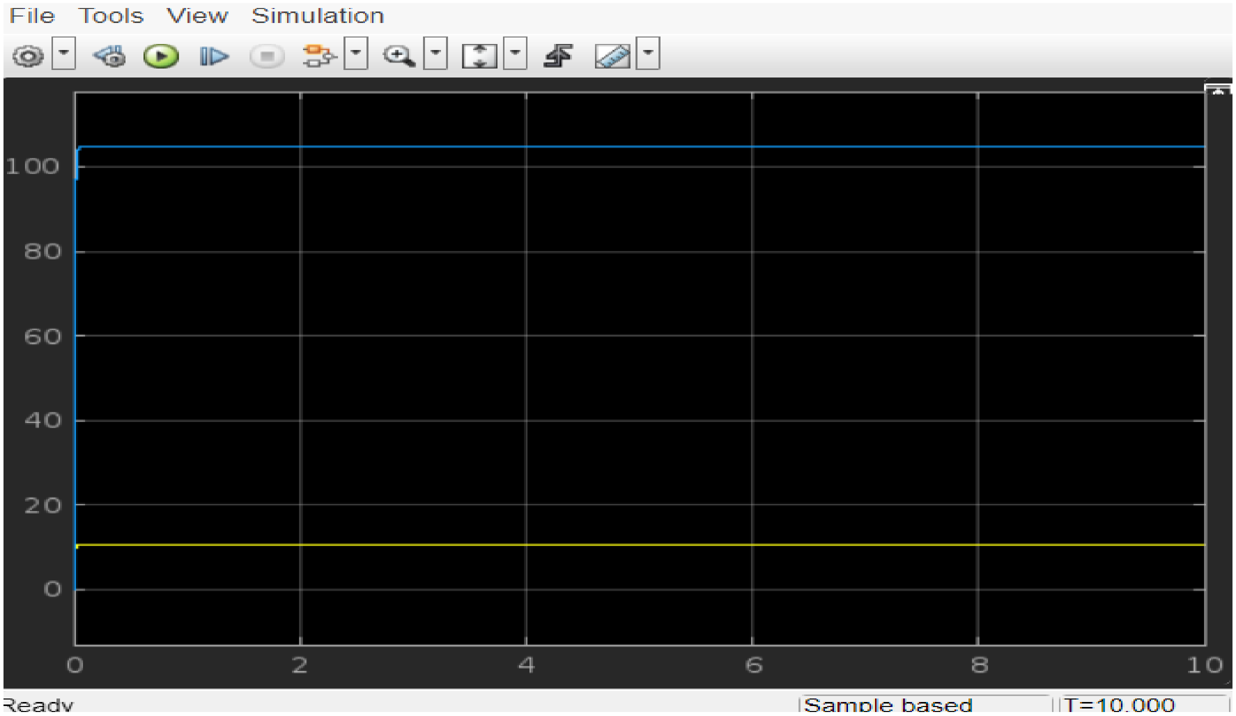


Fig : Capacitive Wireless Charging

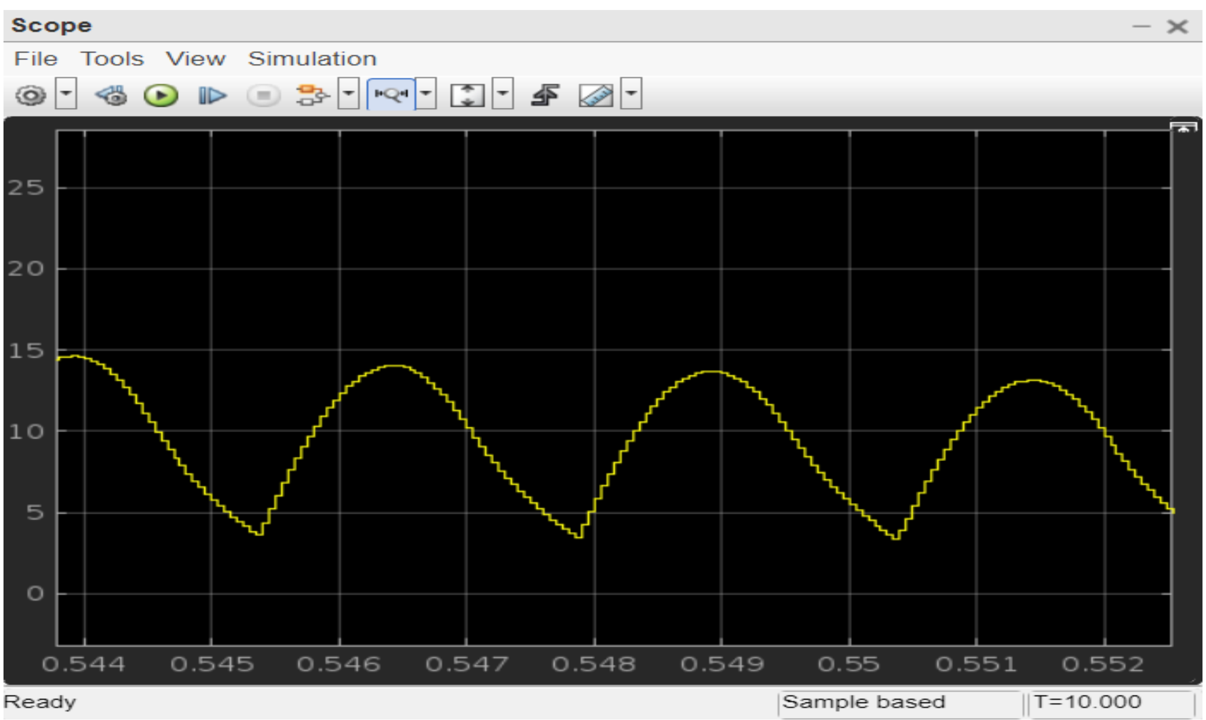


Fig : Microwave Wireless Charging

CONCLUSION

We have explored and compared the three different wireless charging techniques, namely inductive, capacitive, and microwave wireless charging, along with magnetic coupling, RAPT, and RIPT techniques. We have also conducted a MATLAB Simulink simulation for each method and thoroughly researched the mathematical calculations involved.

From our analysis, it is evident that microwave wireless charging has the highest range compared to the other techniques, but it is more complex and requires careful consideration of safety measures. On the other hand, inductive and capacitive wireless charging have lower ranges, but they are simple and widely used in consumer electronics.

We have also found that magnetic coupling, RAPT, and RIPT techniques can deliver similar power output as inductive wireless charging while offering better efficiency and reduced electromagnetic interference.

Overall, the selection of a wireless charging technique depends on various factors such as power requirement, distance, safety, and compatibility with the device. Each technique has its advantages and disadvantages, and the best option should be chosen based on the specific use case.

In conclusion, our report provides a comprehensive understanding of different wireless charging techniques and their mathematical calculations, enabling researchers and industry experts to make informed decisions while developing wireless charging solutions.

FUTURE WORK

The study presented in this report has provided a detailed analysis of different wireless charging techniques and their mathematical calculations. However, there are still areas where further research can be done to improve the efficiency and practicality of wireless charging.

One potential avenue for future work is the development of new wireless charging technologies that can deliver higher power output and longer range. While microwave wireless charging has the highest range, it is also the most complex and poses safety concerns. Therefore, there is a need for research to explore alternative wireless charging technologies that can deliver higher power output with minimal safety risks.

Another area of future research is the integration of wireless charging technology into existing infrastructure, such as roads and public spaces. Wireless charging technology can be integrated into public spaces such as airports, shopping malls, and coffee shops to provide a seamless charging experience for users.

Finally, there is a need for research to explore the use of wireless charging in industries such as healthcare and automotive. For instance, wireless charging can be used to power medical devices and electric vehicles, which can significantly reduce the need for cables and improve convenience.

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