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Investigation on Optimal Distance between Transmitter and Receiver Coils in Wireless Power Transfer for Dynamic Charging System

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ABSTRACT

The usage of electric vehicles (EVs) has significantly increased because of the worldwide movement toward environmentally friendly transportation. Notwithstanding these advancements, creating a comfortable and effective infrastructure for charging EVs remains a significant obstacle to their broad adoption. To overcome this difficulty, wireless power transfer (WPT) technology—specifically, WPT-DCS—has shown promise. With Wireless Power Transfer (WPT)- Dynamic Charging System (DCS), physical connectors are no longer necessary, and EV batteries may be refilled while on the road. In this paper, the development of an optimal distance for wireless power transfer in a dynamic charging system for electric vehicles is proposed. Research that investigated square and circular spiral coils to solve the challenges of WPT-DCS implementation focused on the effects of spiral geometries' thickness as well as the magnetic flux distribution, coupling factor, the receiver (RX) efficiency, RX power, and mutual inductance between TX (transmitter) and RX. Determining the ideal distance between TX and RX and TX and TX is the main goal for dynamic EV charging systems. This paper also presents the hardware setup that replicates the dynamic charging environment for square and circular spiral coils. The concept of emf generation and its utilization for charging the battery while the vehicle is in motion is presented in this paper.

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1. INTRODUCTION

The reliance on public transportation has grown over the last several years, which has increased emissions and hazardous gas emissions [1]-[2]. Finding substitute ways to power cars with fossil fuels was imperative. Electric vehicles (EVs) are an alternative that lessens reliance on fossil fuels, reducing harmful gases and protecting the health of living things. WPT technology is used to wirelessly charge the battery of an electric vehicle [2]. This technology operates automatically, doesn't require the user to exert any effort, and can be used in harsh weather conditions like wind, rain, and snow. It also eliminates the need for any connecting wires during the charging process. There are two types of charging static and dynamic charging: Static refers to a 'vehicle is in stationary on a designated charging zone', while dynamic means 'vehicle is in driving state during charging' like along an electric wireless highway [3].

There are three methods available for charging electric vehicles. The first method, known as stationary charging, involves charging an automobile while it is stationary, such as in a private garage or parking lot [4]-[6], [17]-[18]. Regarding the second kind of charging, known as dynamic charging, the car is moving while it is being charged on a highway with specific charging lanes assigned to it. The third kind, known as quasi-dynamic charging, can take place during transit stops like traffic light stops or when the vehicle is travelling at a slow speed. The dynamic wireless charging of an electric vehicle is made possible when the vehicle is operating on this road and has a receiving coil installed. This allows the power grid to be continuously transferred to the driving motor of the electric vehicle. Research institutes have been paying more and more attention to electric vehicle dynamic wireless charging technology in recent years due to its long endurance mileage, small on-board battery carrying capacity, and flexible charging methods [7]-[9]. Figure 1 shows the DCS of electric vehicles. Figure 2 shows the schematic view of the placement of transmitters and receivers. In case A, the maximum power transfer has been analysed for various distances between the transmitter and receiver. In case B, the maximum power transfer has been analyzed between the transmitters and transmitters to receiver.

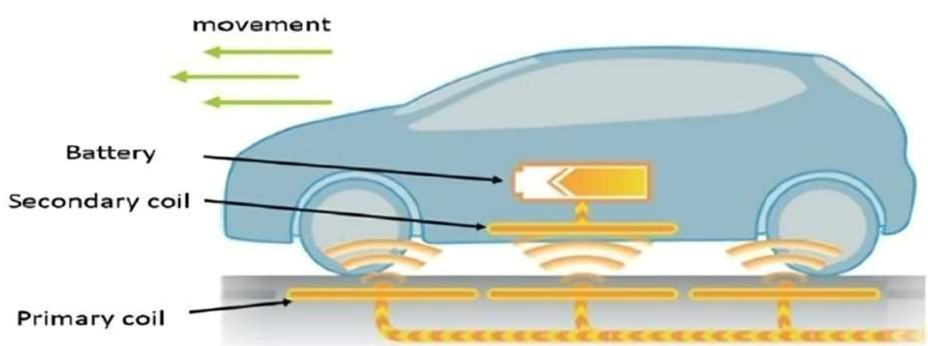


Figure 1. A pictorial representation of dynamic charging system of an electric vehicle.

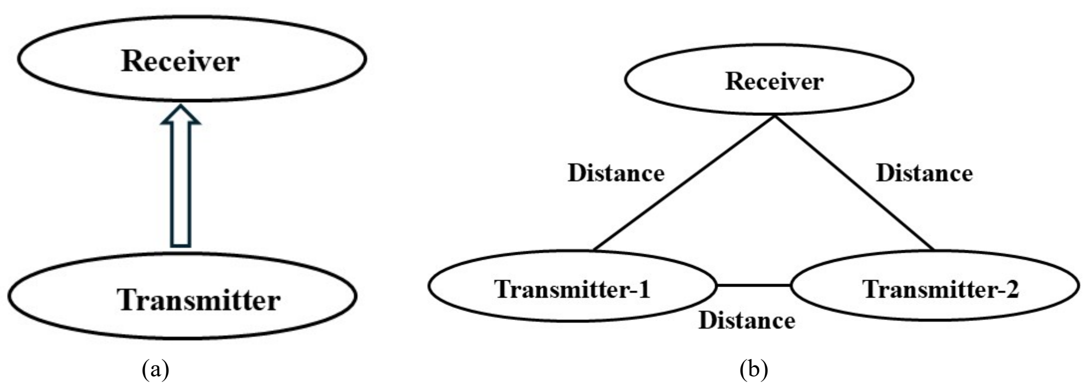


Figure 2. Schematic view of the placement of (a) Case A: Transmitter and (b) Case B: Receivers.

Research to create extremely effective EV wireless charging systems that optimize power transfer efficiency is presently underway on a global scale. Maintaining the EV's alignment with the road-embedded charger is the main challenge for dynamic charging. Because the electric vehicle must travel on roads, there is a wide range in the coupling. Carrying out a parametric analysis of the primary and secondary coils mutual inductance [10]-[12].

The typical WPT system for electric vehicles is shown in Figure 3. The magnetic coupler is made up of primary and secondary coils. The primary coils in the Dynamic Wireless Power Transfer (DWPT) system for electric vehicles (EVs) should be well-designed and optimized to achieve high output power, high efficiency, and low electromagnetic field (EMF) to improve the dynamic performance of the magnetic couplers in the system [3]. The magnetic coupler for the DWPT system can be divided into two groups based on the types of coil structures. Long rails are the first kind, and coil arrays are the second. Long rail has problems with high EMI and low efficiency. The coil array is therefore more efficient [13]-[16].

This paper demonstrated that the efficiency of the square spiral coil surpassed that of the circular spiral coil, highlighting the significance of coil geometry in WPT-DCS for EV charging. This paper also addresses this challenge by investigating the optimal distance that maximizes power transfer while remaining practical and safe for dynamic electric vehicle charging. The hardware setup, functional layout, and the analysis of different coil designs for WPT-DCS is demonstrated.

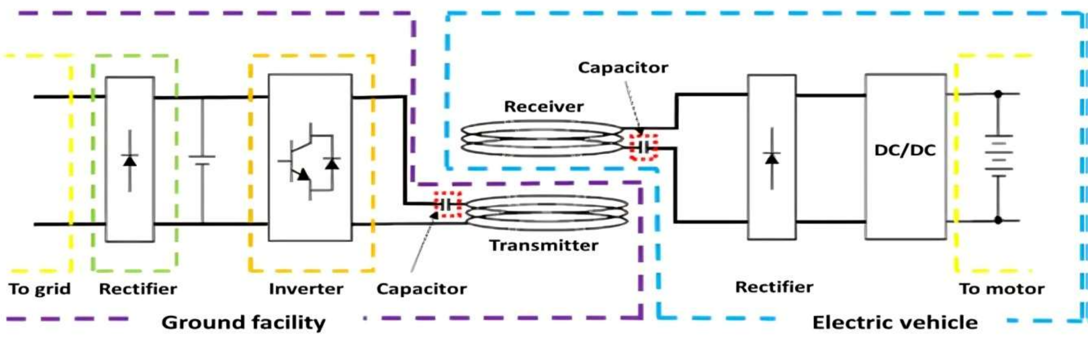


Figure 3. Typical WPT charging system for electric vehicle.

2. IMPLEMENTATION OF DYNAMIC CHARGING SYSTEM FOR ELECTRIC VEHICLES

In this section block diagram of the dynamic charging system for EV, the components required for the practical implementation of WPT, various shapes of the coils, experimental setup and working of the system are presented. The block diagram shown in Figure 4 demonstrates the flow that is to be done for the achievement of dynamic wireless power transfer of electric vehicles. Initially, AC supply gives AC voltage, then converting from AC to DC adaptor is used which acts as a rectifier. Then that DC voltage is given to the transmitters, but transistors present in between the transmitters and adaptor that again converts DC to AC. The receiver which will be in the vehicle receives AC power from the transmitters. So, the bridge rectifier is used for the conversion of AC to DC, and the same will be stored in the battery. Additionally, voltage sensors are used to sense the voltage which will be displayed on the LCD display using Arduino uno. And the current sensor is used to sense the current through LEDs which will be displayed on the LCD display.

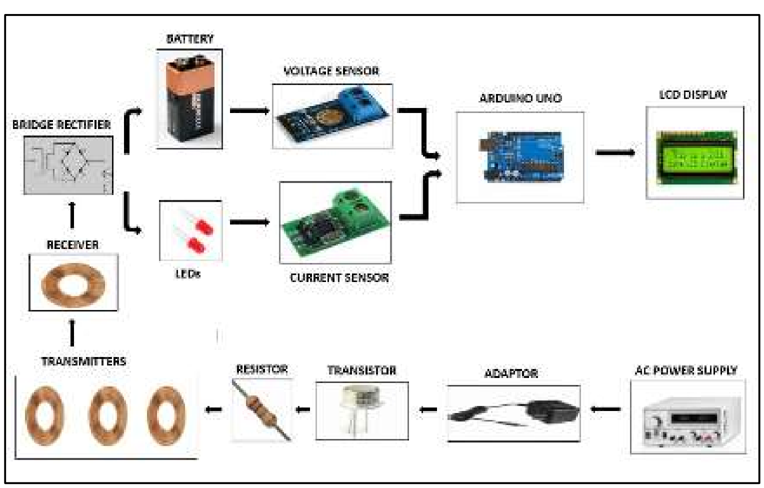


Figure 4. Block Diagram of Dynamic WPT.

3. DESIGNING DETAILS OF THE COILS

Before finalizing the shape of the coil, various designs of the coils are tried like Square Spiral Coil, Circular Spiral Coil and Circular Coil with the copper wires of different thicknesses.

3. 1. Square Spiral Coil

First the square spiral coil is made of 10 turns with a copper wire of thickness 2mm with 1mm gap between each turn. By using the coils shown in Figure 5, unable to get the expected output because of the gap between each turn which disturbs the uniformity of the magnetic field which leads to less conductivity that is responsible for less power transfer.

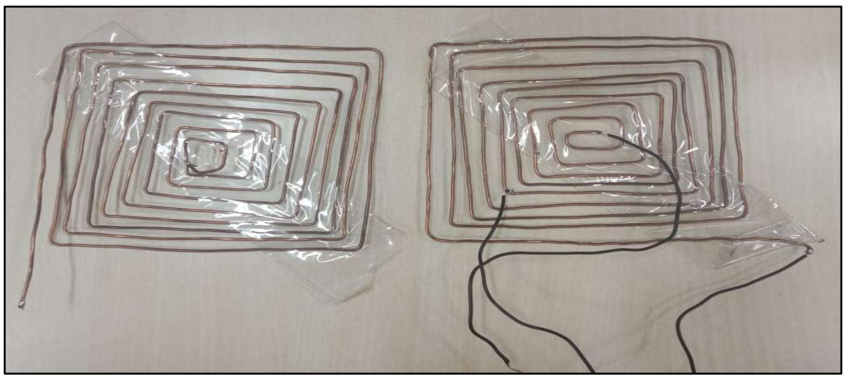


Figure 5. Square spiral coil of 10 turns with thickness of 2mm with 1mm gap.

3. 2. Circular Spiral Coil

Circular spiral coil is made of thickness 0.5mm and the gap between each turn is 1mm. This coil with less thickness of 0.5mm is made thinking that square spiral coil and helical coils are not working because of the high thickness. By using circular spiral coils with less thickness also as shown in Figure 6, unable to get the expected output. This coil is made thinking that square spiral coil and helical coils are not working because of the high thickness, but unable to get the output using these coils also. Circular spiral coil of 10 turns as shown in Figure 6(a) is not working because of the less turns, and tried for 30 turns of circular spiral coil as shown in Figure 6 (b). As its results observed that the spacing between the turns disturbs the uniformity of the magnetic field that produces less magnetic field which in turn produces less power transfer.

(a) (b)

Figure 6. Circular Spiral Coil (a): 10 turns, (b): 30 turns.

3. 3. Helical Coil

Helical coil is made without gap between each turn. This coil is made thinking that square spiral coil and circular spiral coils are not working because of the gap between each turn. By using the helical coils shown in Figure 7(a), unable to get the expected output because of more thickness. Using the helical coil as shown in Figure 7(b), got the expected output because that coil is made without any gap between each turn, with less thickness and more turns which produces more magnetic field and transfers more power. So, finalized the helical coil with 50 turns.

(a) (b)

Figure 7. Helical coil: (a) 10 turns with 2mm thickness (b) 50 turns with 0.5mm.

4. TRANSMITTERS

For dynamic wireless power transfer, electric vehicles must be charged while it is in motion, hence it is necessary to embed multiple transmitters on road for continues charging without any break. The transmitters are arranged one after the other as shown in Figure 8 with the distance between two coils of 100mm. It is visible that the coils are made with the specifications that are finalized before that is of thickness 0.5mm, 50 turns and without any gap between each turn.

Figure 8. Installation of Transmitter coil on road.

5. EXPERIMENTAL SETUP

The experimental setup shown in Figure 9, has exactly done same as the block diagram shown Figure 4, which shows the flow of the steps that are to be followed to get the expected result. The hardware experimental setup includes multiple transmitters that are embedded on the road with the distance of 100mm which will power up through AC supply, and the receiver in the vehicle which will power up when it comes near around 40mm above the transmitters and also the power received from the receiver converts to DC using bridge rectifier and same will be stored in the battery.

The experimental setup of dynamic wireless charging system shown in Figure 9 where the transmitter is embedded in the road surface and receiver coil is underneath car module. Transmitter coils are getting supply of DC where transmitter coil is connected to transistor and resistor where the transistor works as switch and resistor are used to control high current gain. Due to transistors DC is getting converted to AC. This AC current is transmitted to receiver coil and to convert AC to DC bridge rectifier and capacitor is used this output is connect to batteries to storage the voltage to run the vehicle, when car is in movement LED will glow to indicates currents is flowing in the circuit. Current sensors and voltage sensors are used to measure the current and voltage. Arduino code dumped into Arduino to display the voltage and current, these are the two main values displayed on the LCD as shown in Figure 10. Voltage is a representation of the electrical pressure driving the current, while current is a measure of the rate at which electricity moves. Through the monitoring of these parameters, this can guarantee the safe and efficient operation of the system.

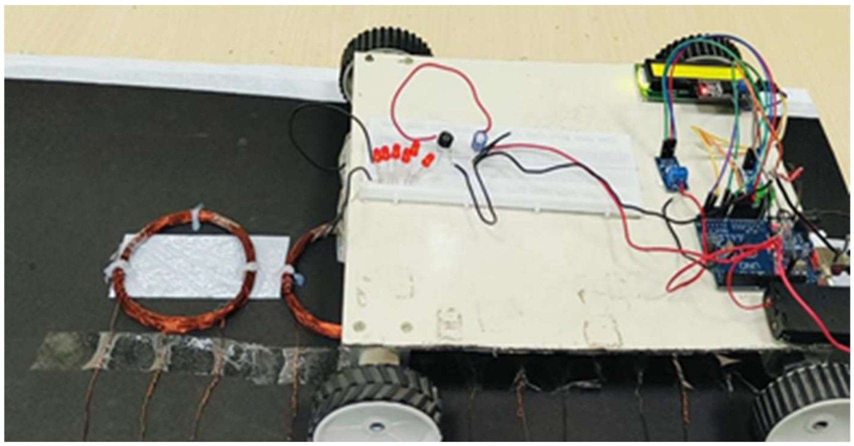


Figure 9. Experimental Setup of Dynamic WPT.

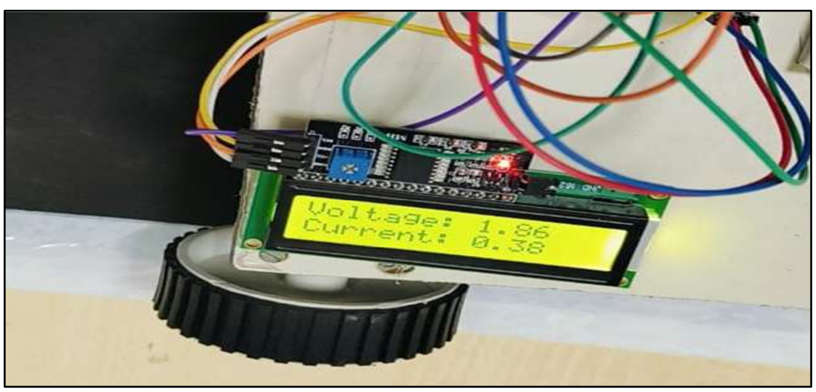


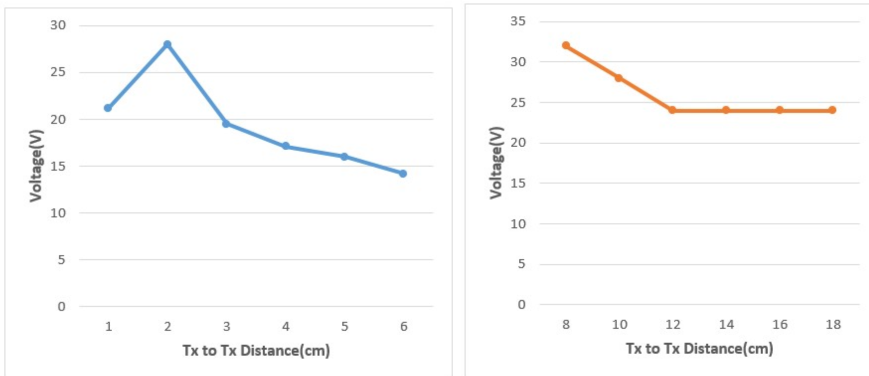
Figure 10. Output of voltage and current on LCD display.

6. RESULTS

The analysis between the TX to TX when the TX to RX distance is kept constant at 3cm distance, the result can be seen in Figure 11(a). TX to TX distance from 8 cm to 18 cm, through this voltage is observed in Figure 11(a) which has highest voltage of 18.2V at the 10 cm distance.

The analysis between the TX to TX when the TX to RX distance is kept constant at 4cm distance, the result can be seen in Figure 11(b). By varying TX to TX distance from 8cm to 18cm, through this voltage is observed in Figure 11(b) which highest voltage of 32V at the 8cm distance. This analysis is carried out between the various TX to TX when the TX to RX distance is kept constant at 3cm, 4cm, 5cm and 6cm distance, the result can be seen in Table 1.

From the simulation it is observed that a maximum of 438mA of current can be achieved from the developed WPT shown in Figure 12. In electric vehicles' time of charge become more important, the proposed DWPT takes 60 mins for the voltage and current of 1V and 20.3mA for 9V battery is shown in Figure 13. The current graph is opposite it to voltage graph when connected to load. As from Figure 13(b), the highest value of 20mA is obtained for 10 minutes.



(a) (b)

Figure 11: (a) Results for TX to RX distance 3cm, (b): Results for TX to RX distance 3cm.

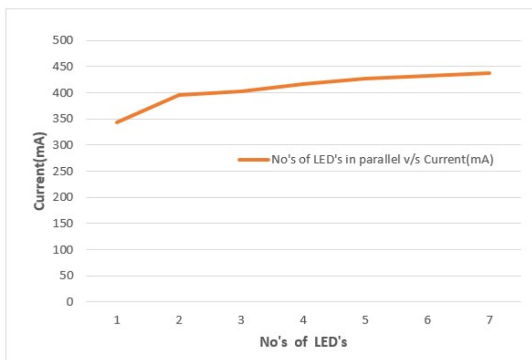
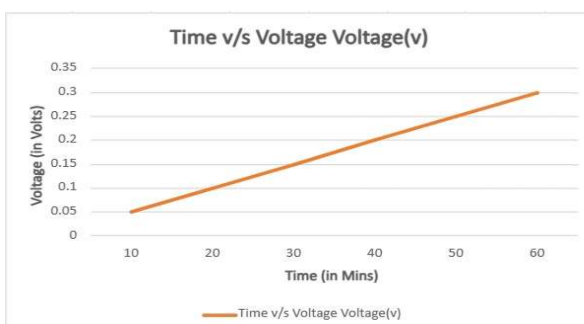
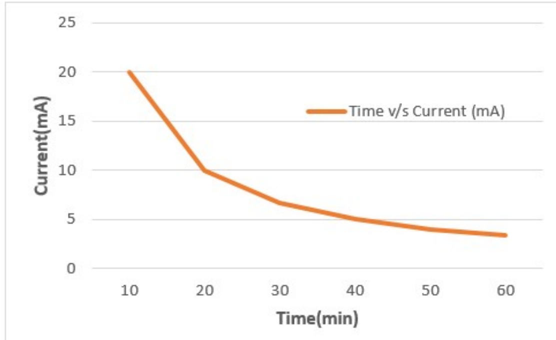


Figure 12. Number of LEDs in parallel Versus Current (mA).



(a)



(b)

Figure 13. Charging over time (a): voltage, (b): current charging over time.

Table 1. Change of voltage between TX to RX for different distance.

TX to TX distance(cm)	V in 3cm	V in 4cm	V in 5cm	V in 6cm
8	16.4	32	16.4	10.4
10	18.2	28	18.2	18
12	18.1	24	18.1	10
14	17.9	24	17.9	16
16	17.2	24	17.1	10
18	15.3	24	15.3	14

7. SIMULATION STUDY

A helical coil is a three-dimensional spiral structure modelled in COMSOL Multiphysics as shown in Figure 14. Iron-core Coil is modelled for High permeability core for increased inductance. Coils placed near each other induce currents through electromagnetic coupling. Figure 14 shows the middle transmitter, middle transmitter to left side which is in negative range and middle transmitter to right side, which is in positive range.

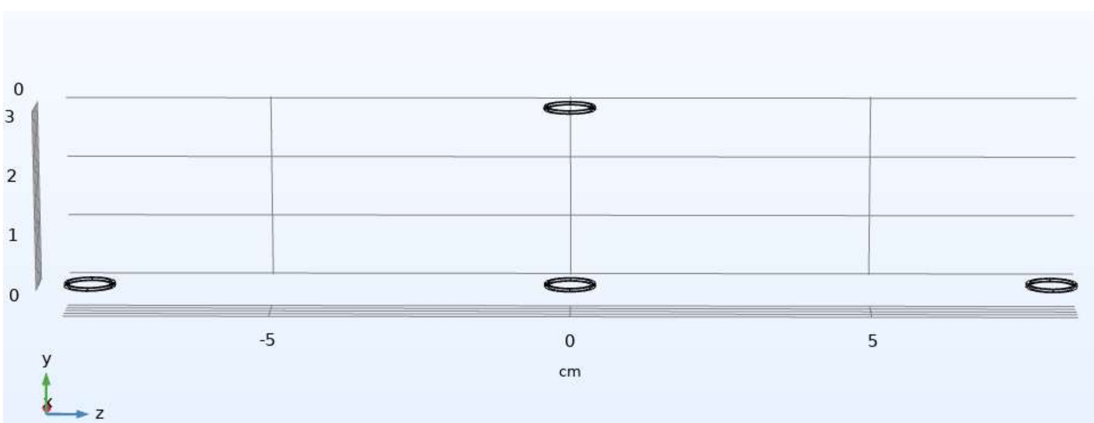
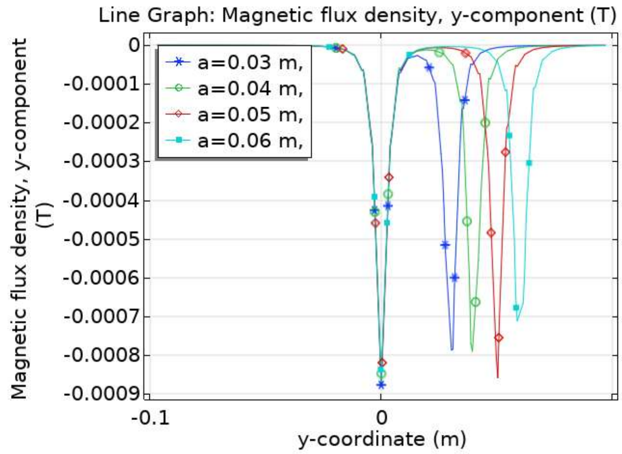
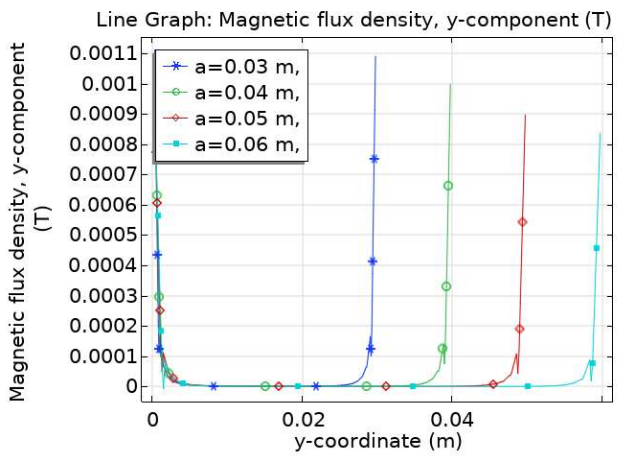


Figure 14. Simulation 3D Model of Helical Coils of TX and TX; TX and RX.



(a)



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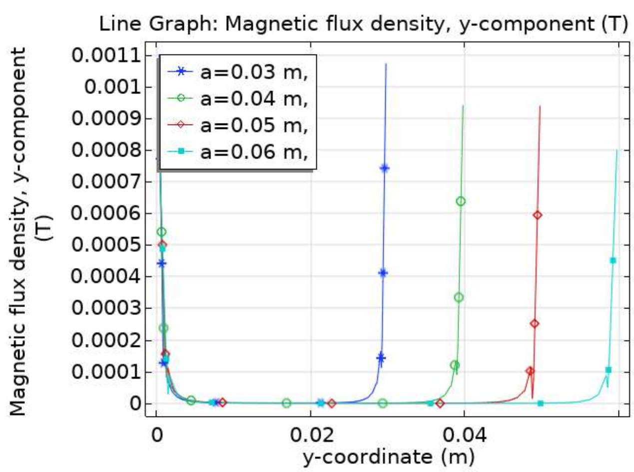

(c)

Figure 15. Magnetic flux distribution between (a): Middle of transmitter and receiver (b): Left transmitter to middle transmitter (c): Right transmitter to middle transmitter.

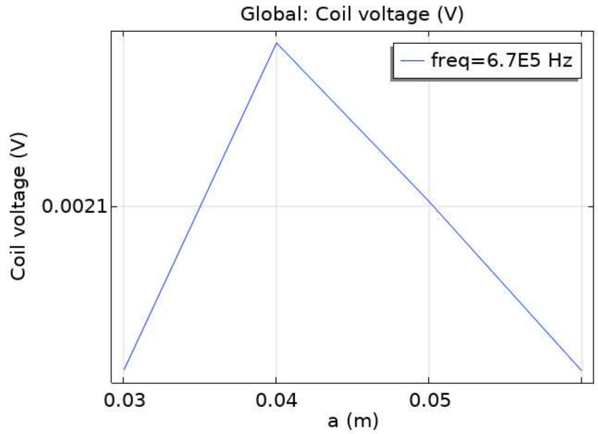

Figure 16. Voltage observed at receiver coils.

The magnetic flux distributions are analyzed between the transmitter and transmitter at 8cm. The magnetic flux distribution is analyzed between the middle of transmitter to receiver as shown in Figure 15(a). When the distance between the transmitter to receiver increases, then the magnetic coupling between the coils decreases. The magnetic coupling between the left and right transmitters to receiver is same and constant in both figures 15(b) and 15(c). The magnetic coupling between the receiver and middle of transmitter is less compared to other transmitters due to magnetic mutual interferences.

The voltage between the transmitter and receiver is at maximum 4 cm as shown in Figure 16, as similar to the experimental results depicted in Table 1. The coil voltage is high for the middle transmitter to receive coils.

8. CONCLUSION

The paper emphasizes developing the WPT for electric vehicles, particularly focusing on optimal distance between coils. By evaluating various coil designs, that helical coil with 50 turns offered the best results. The system successfully transferred a magnetic field to the receiver coil, inducing a current for battery charging. The study showcases the viability of wireless charging for electric vehicles in motion, potentially revolutionizing the EV charging landscape. Various coil designs were analyzed to enhance wireless charging efficiency for moving electric vehicles. The research gap included reducing EMI, enhancing coil misalignment tolerance, and evaluating compensation strategies for effective power transmission. From the results it is inferred that the magnetic coupling between the transmitter and receiver decreases when the other transmitters are near to each other. The optimal distance between the transmitter and transmitter is achieved for 50 turns is 8 cm and observed voltage at receiver is 32 V.

DECLARATIONS

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