Wireless Charging of Electric Vehicle

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ABSTRACT

Around the world, static wireless charging is rapidly gaining popularity as a way to recharge electric cars (EV). But even a fully charged electric vehicle has a finite driving distance. More batteries are required in order to increase its operating range. It is now possible to extend the range of an electric car without adding heavy batteries by using dynamic wireless charging. One kind of vehicle that could avoid this issue is the modern electric car. On the other side, Dynamic WPT will render obsolete a plug-in charger and static WPT, thereby tripling an EV's total range. Since we can charge an EV while we are travelling, we won't need to stop or worry about running out of electricity. In the future, batteries from hybrid, electric, and other vehicles may be recycled using this method. You will need a transmitter coil and a receiver coil in order to utilise wireless charging. Mutual induction will allow the transmitter coil to provide electricity to the receiving coil as it passes both. On the other hand, the distance between two adjacent coils influences wireless power transmission (WPT). Using Analysis Maxwell simulation software and a system made up of two Archimedean copper coils, we examine the effects of vertical and horizontal misalignment on the WPT. At a 150 mm air gap, the transfer power is 3.74 kW with a 92.4 percent efficiency. A 6.1 kW electric vehicle's battery is fully charged in around 1 hour and 39 minutes when there is a 150mm air gap. Dynamic charging is also made easier by having a designated charging lane. When operating an EV in a charging lane, the power transfer is calculated using mutual inductance. To determine how far an EV can go with this extra power, one may utilise the load power.

Key Words: Electric vehicle, wireless power transfer, dynamic charging, efficiency, charging lane

1. INTRODUCTION

The first electric vehicle was released by General Motors in 1996, and that was the start of the electric vehicle revolution. On the other hand, with the debut of Chevrolet and Nissan, EV manufacturers have taken a technologically amazing and socially acceptable stride forward in the name of environmental responsibility. A major step in protecting the environment, enhancing the dependability of transportation, and reducing dependency on fossil fuels is switching to electric vehicles. Because of this considerable benefit, an increasing number of firms are investing heavily in researching and enhancing electric car technologies. Built on the concept of wireless charging is the Wireless Charging System (WCS). An induced EMF in the second coil, known as the reception coil, may be used to generate electrical energy with a certain current in the first coil, known as the transmitter coil [1]–[5]. As a result of advancements being made in this field by automakers and research organisations, charge while driving (CWD) infrastructure may become generally available over the next ten to twenty years. As a result, a number of firms are looking at methods to improve the charging process for electric automobiles while also increasing their range. System for paper design with resonance frequencies ranging from 40 to 85 kHz (S-S, or series-series). According to the experts, WPT technology performs best in low-power electric vehicles. On the other hand, one of the key problems facing EV producers is dynamic charging. Since the invention of wireless charging for electric cars, two WPT strategies have shown to be highly effective. Both capacitive wireless power transmission (CWPT) and resonant inductive power transfer (RIPT) have been shown to be effective substitutes for conventional electrical power distribution systems (RIPT). Studies have shown that inductive charging is substantially more effective than capacitive charging and has a higher power density. The magnitude of the inductive properties is influenced by the coupling coils' diameters. Many researchers are looking into how to provide more power to the receiving pad in order to boost the efficiency of electric cars in dynamic situations. However, most work is inefficient, and RIPT is no different. When operating an electric car, misalignment is another element that reduces overall efficiency. Efficiency falls when there is a coil mismatch between the transmitter and receiver. The coupling coefficient rises from 0.2 to 1.6 for a 20% misalignment of the coils. Several shielding materials may be used to achieve the desired results of magnetic field alignment and leakage flux reduction. A ferrite item has been shown to diminish magnetic fields while having minimal impact on neighbouring objects. The coil may also have an impact on the crystal structure of the ferrite. Circles, striated circles, squares, rectangles, T-cores, U-cores, E-cores, Double Us, and striated blocks [6] through [10] are just a few of the forms and sizes that are available. Due to their high battery capacities, EVs' WCS may be able to deal with concerns about range, battery shortages, and wasted space. Dynamic WCS, on the other hand, encounter challenges such worse efficiency, decreased power transfer, bulkier design, and electromagnetic compatibility. On the other hand, dynamic WCS has been investigated to address the reduced range of concern related to a continuous charging facility. This technique allows the battery storage unit to be charged while the EV is in motion. In this case, the automobile just needs a limited amount of battery storage. In order to enable wireless charging, also known as dynamic charging, Wireless Charging Units (WCUs) are positioned on the road so that energy is captured by mutual induction as a car passes over them. To address the issue's restricted range, increase the transit range of electric vehicles. Dynamic WCS is hindered by two major issues, though: horizontal misalignment and a large air gap between the EV and the charging channel. Coil alignment and air-gap distance inside the coils have a significant impact on the efficiency of power transmission. When the distance between two coupling coils is kept as small as possible, more energy may be passed between them. Circular pads (CP), circular rectangular pads (CRP), double-D pads (DDP), double-

D quadrature pads (DDQP), and bipolar pads are among the coil topologies (BPP). It has been shown that the inductive system utilising DD and QDQ coils maintains maximum efficiency whether the coils are positioned correctly or incorrectly. The typical air gap for small automobiles is between 150 and 300 mm. This article's emphasis is on simulation and computation in these ranges as a result. However, it could go up for larger cars [11]–[13]. This study offers a comprehensive discussion of dynamic WPT under the mutual induction paradigm. Then, the transmitter and receiver coils are modelled using Ansys Maxwell software, and WPT simulation is run. Ansys Maxwell can simulate and model electromechanical parts, including transformers, electric machines, and wireless charging, to mention a few. As a result, a mathematical equation should be used to confirm the final results. Additionally predicted are the system's effectiveness and energy use. The amount of energy an electric vehicle can take in from a charging lane as well as how far it can go after its stored energy has been used up are calculated in the last step. Numerous research have focused on simulating and calculating WPT transmitter and receiver coils.

2 .WIRELESS POWER TRANSFER

An inductive coil is used to transmit electricity in the IPT technique. The static approach for WPT is the most effective when the receiver coil is centred above the transmitter coil. However, when considering dynamic charging, the receiving coil moves and can only collect a certain amount of magnetic flux from the transmitter coil (see Fig. 1). The transmitter and receiver coils are brought into resonance using a capacitor on the transmitter side and a compensation network on the receiving side. The RIPT method is the name given to this process. The most effective method for wirelessly transferring electricity over short distances is called RIPT. Series-series (s-s), series-parallel (s-p), parallel-parallel (p-p), and parallel series (p-s) compensation networks are the four compensation networks used in the RIPT technique. The s-s compensation network is used in this study because it provides the receiving pad with the most power. The switching frequency of RIPT [13]-[15] is likewise greater than that of IPT.

Grid power is converted from low frequency (lf) to high frequency (hf) ac using an ac-dc converter and a dc-ac inverter. Using the s-s compensating technique, both the transmitter and receiver coils may send as much energy as is practical to the reception. The receiving pad will typically be placed on the vehicle's floor, while the sending pad will typically be positioned below the road's surface. The receiver pad is often positioned lower on the EV's frame in order to gather more magnetic flux. To charge the batteries, high-frequency AC is converted into DC via an AC/DC converter. The battery management system (BMS) communications and power controller are used to keep everything running smoothly and safely. The whole charging procedure from the grid to the car is shown in Figure 2 from [14] to [15]. (G2V).

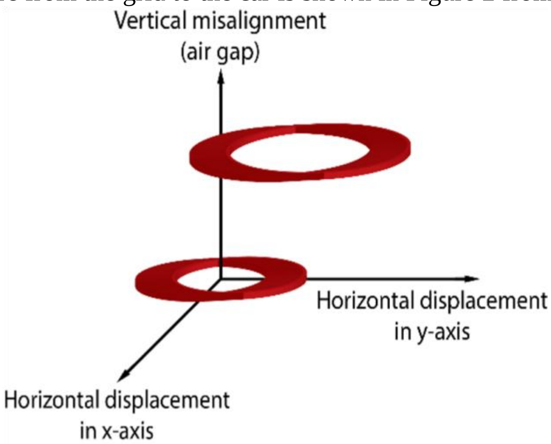

FIGURE 1. Misalignment of the transmitter and reception coils.

3. COIL DESIGN

In WPT systems, many types of coils are used. The circular coil is the best arrangement for high-frequency wireless communications since it has any sharp edges. The eddy current is thus kept to a minimum. The WPT technology operates more effectively as a result of the coil's strong magnetic field. The intended transmitter coil and receiving coil are shown in Figure 5.

4. EQUIVALENT EQUATIONS

After being built, an Archimedean spiral coil is challenging to alter. Proper modelling is needed for an Archimedean spiral coil. An Archimedean coil's inductance is computed in a different way than a circular coil is.

The Wheeler formula given in may be used to compute the transmitter coil's self-inductance (1).

The most significant variable in this case is M, or mutual induction. We can determine the quantity of power transferred to the receiving end thanks to mutual inductance, which is crucial for taking subsequent actions. As the coils are moved up and down, the magnetic field and the amount of mutual induction change. Mutual induction will be calculated using the radii of the current filaments in the transmitter coil (Rt) and receiving coil (Rr) (Rr). The subscripts 't' and 'r', which range from 1 to 18, denote the number of turns in the coil; R1 represents the radius of the first turn, and so on. N and Nr denote the number of turns on each coil, whereas D denotes the vertical separation between the transmitter and receiver coils [3, 6]. As a consequence, you may use to get the root-mean-square value of the magnetic flux density B0 (2). To get the total magnetic flux density in the receiving coil, we simply sum the individual figures for each turn.

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$$B_{\circ} = \frac{\mu_o}{4\pi} I_{Trms} \sum_{t=1}^{N_1} \frac{2\pi R_t^2}{\left(R_t^2 + D^2\right)^{3/2}} (2)$$

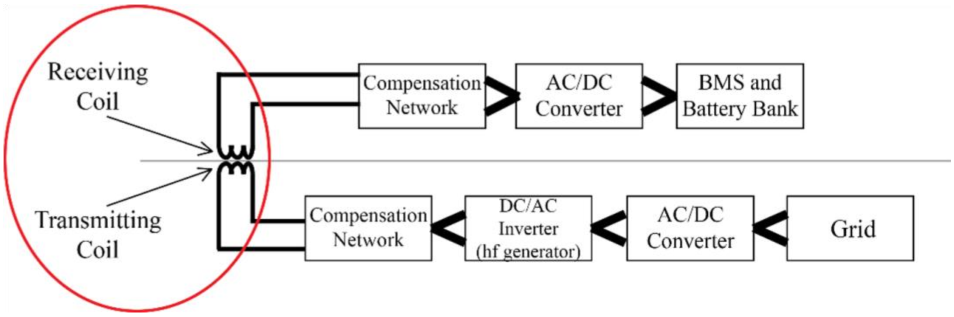


FIGURE 2. Block diagram of G2V

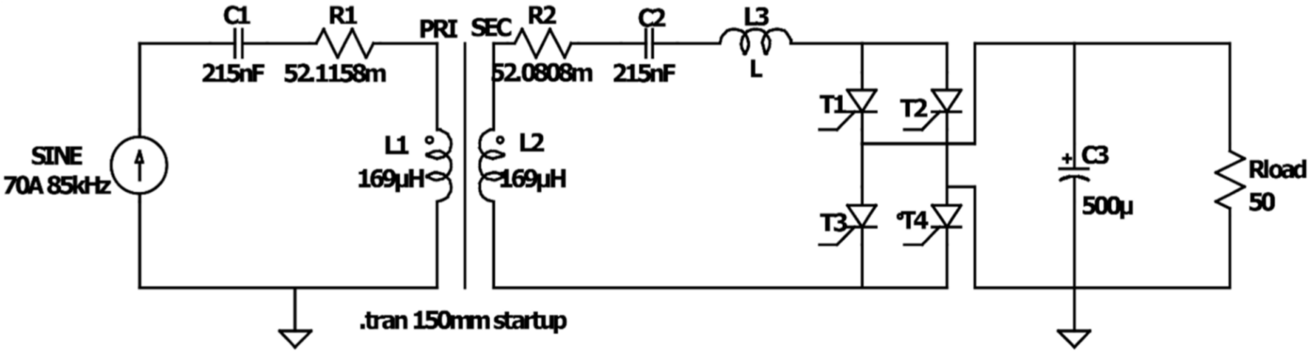


FIGURE 3. RIPT Equivalent Circuit.

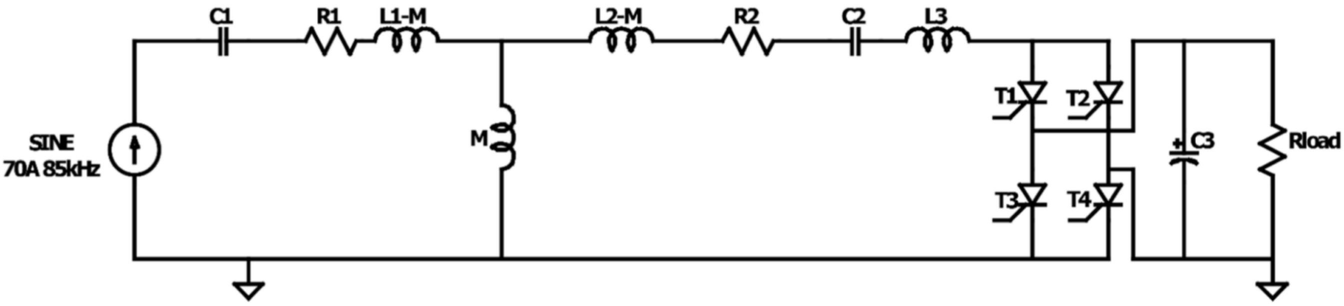


FIGURE 4. Inductance Equivalent circuit diagram

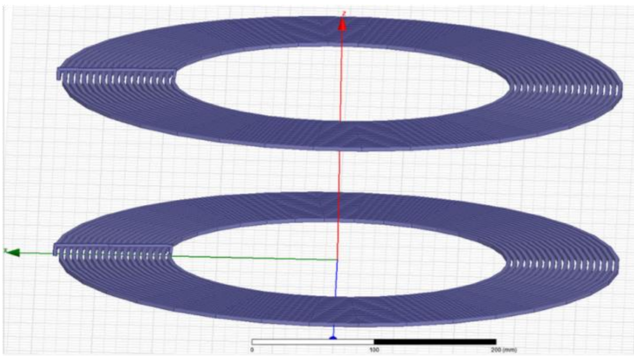


FIGURE 5. Coil both Transmitter and Receiver

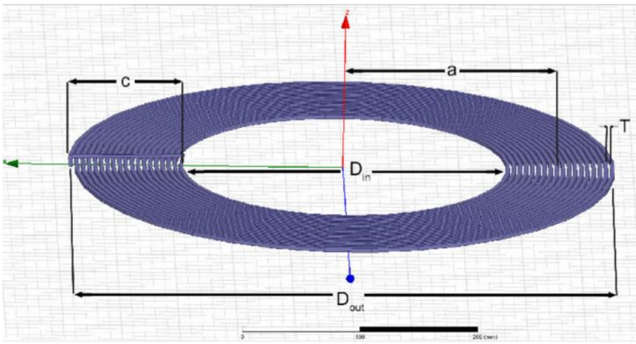


FIGURE 6. Archimedean coil.

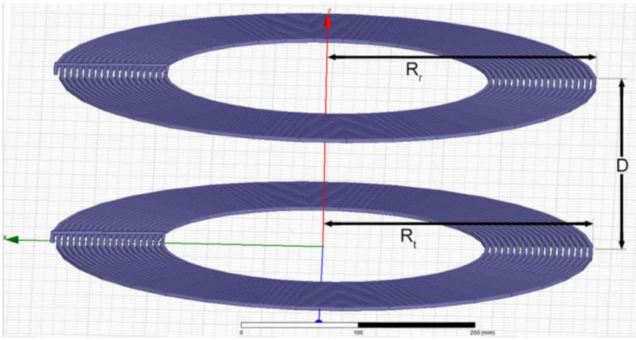


FIGURE 7. Transmitter and receiver coil at D

The final mutual inductance equation, M, is obtained by calculating the total mutual inductance between the transmitter and receiver coils for each turn of the transmitter and receiving ends. (9 may be used to calculate the mutual inductance of two coils regardless of the distance between them.

$$M = \frac{\mu_o}{2}\pi R_r^2 \sum_{P=1}^{N_t} \frac{2\pi R_t^2}{(R_t^2+D^2)^{3/2}} (5)$$

4.3. CALCULATION OF COUPLING COEFFICIENT

The amount of magnetic flux produced by one coil's current that is communicated to another is indicated by the coupling coefficient, or k. In this range, k may have any value between 0 and 1. When k is equal to 1, the flux from one coil is precisely proportional to the flux from any other coil. Additionally called as "magnetically tightly coupled," this phenomena. If k = 0, there is no relationship between the output flux of one coil and the output flux of another coil. It might also be said to be magnetically separated. The magnetic coupling coefficient of Archimedean coils is strongly influenced by the overall winding area. The coupling coefficient may be calculated using the fundamental equations [1] through [5].

$$K = \frac{M}{\sqrt{L_1 L_2}} (6)$$

Here, L_1 andL_2 are self-inductances of the transmitter coil and receiver coil respectively which is from Equation (1).

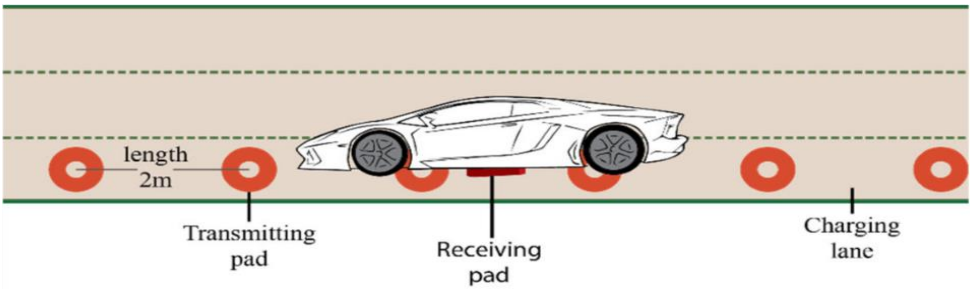


FIGURE 8. Dynamic Charging

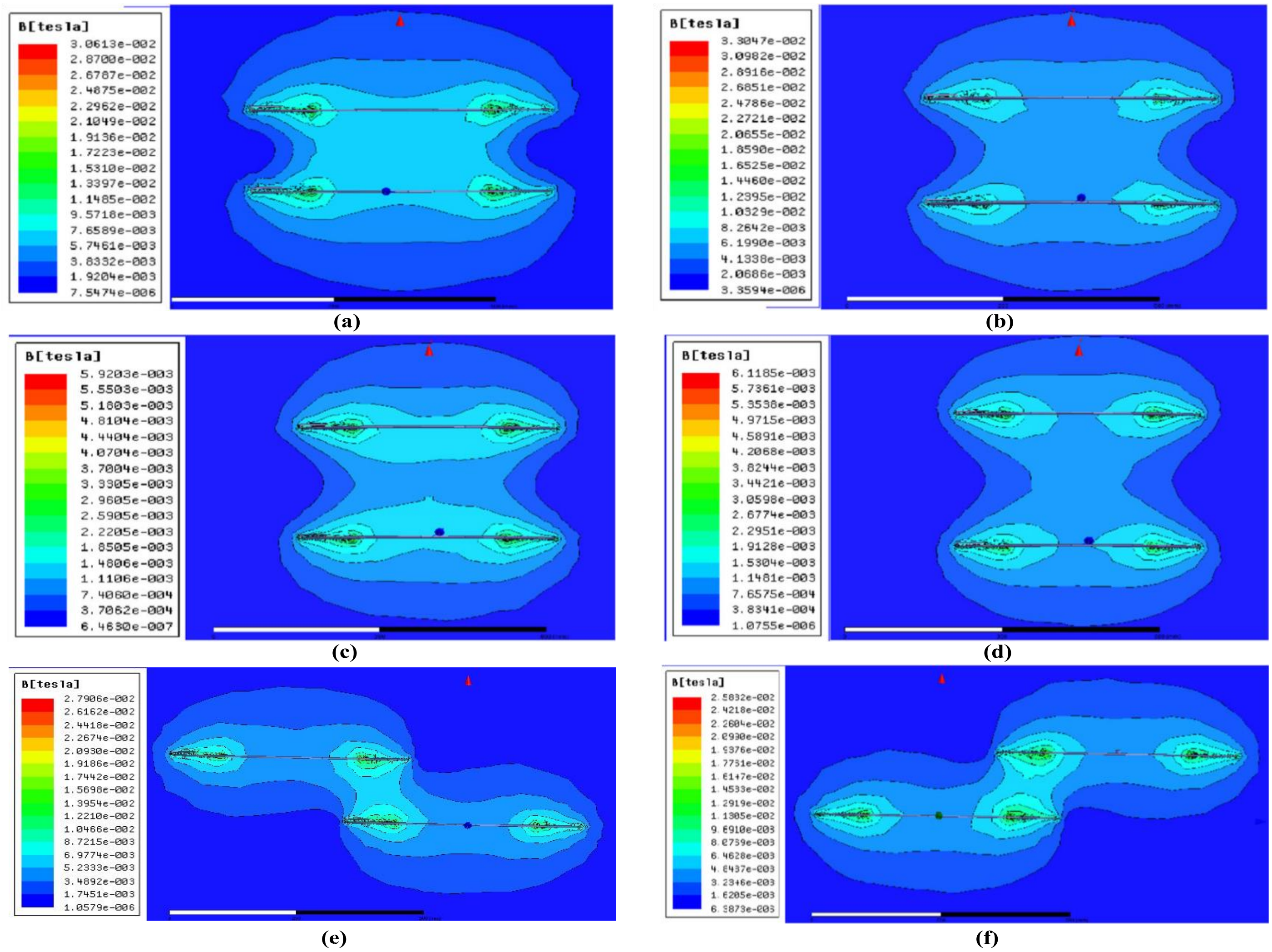


FIGURE 9. Magnetic Flux Density Variation.

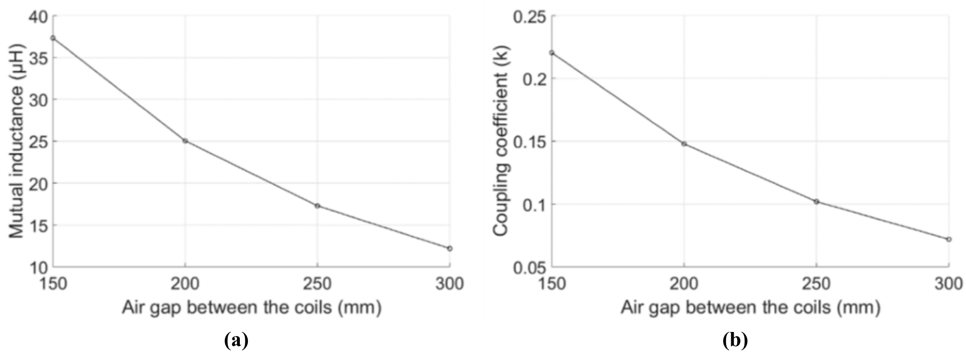


FIGURE 10. Reduction of Mutual Induction and Coupling Coefficient

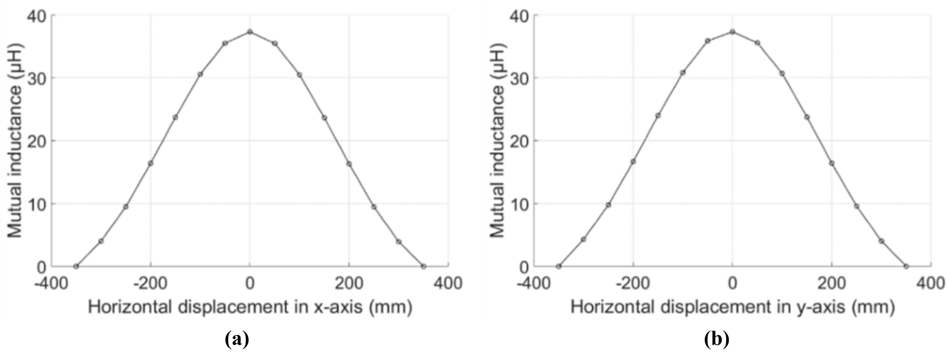
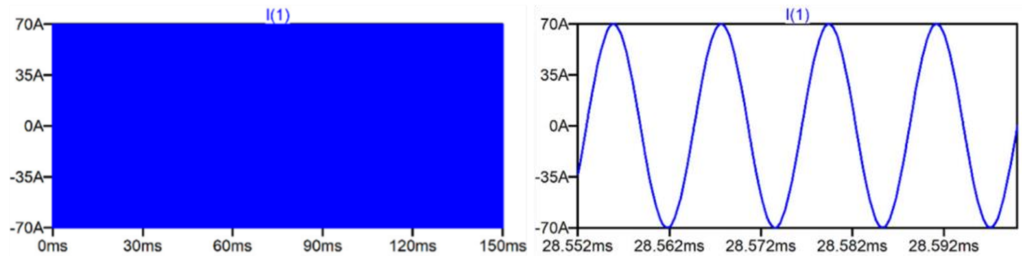


FIGURE 11.Mutual Inductance Variation.



(a) **(b)**

FIGURE 12.Input Current Waveform.

After calculating this equation, the total load power for a single transmitter coil while the receiver coil is moving will be (0.104922)W = 0.20984 W. A 3 kilometre charging lane has been designed for the WPT. 500 transmitter coils will be required for a 1 km section of track if the distance between transmitter coils is 2m, as shown in Fig. 8.

5. RESULTS AND DISCUSSIONS

The simulated data in Fig. 9 after the mutual induction simulation shows how the magnetic flux changes as the air gap widens. As the distance between the coils increases, the area for the transmitter coil's magnetic flux density decreases. The magnetic flux density reception zone of the receiver is thus becoming smaller. The estimated and simulated values are almost comparable, as shown in Table 2, after testing of the transmitter and receiver coils' mutual and self-inductance.

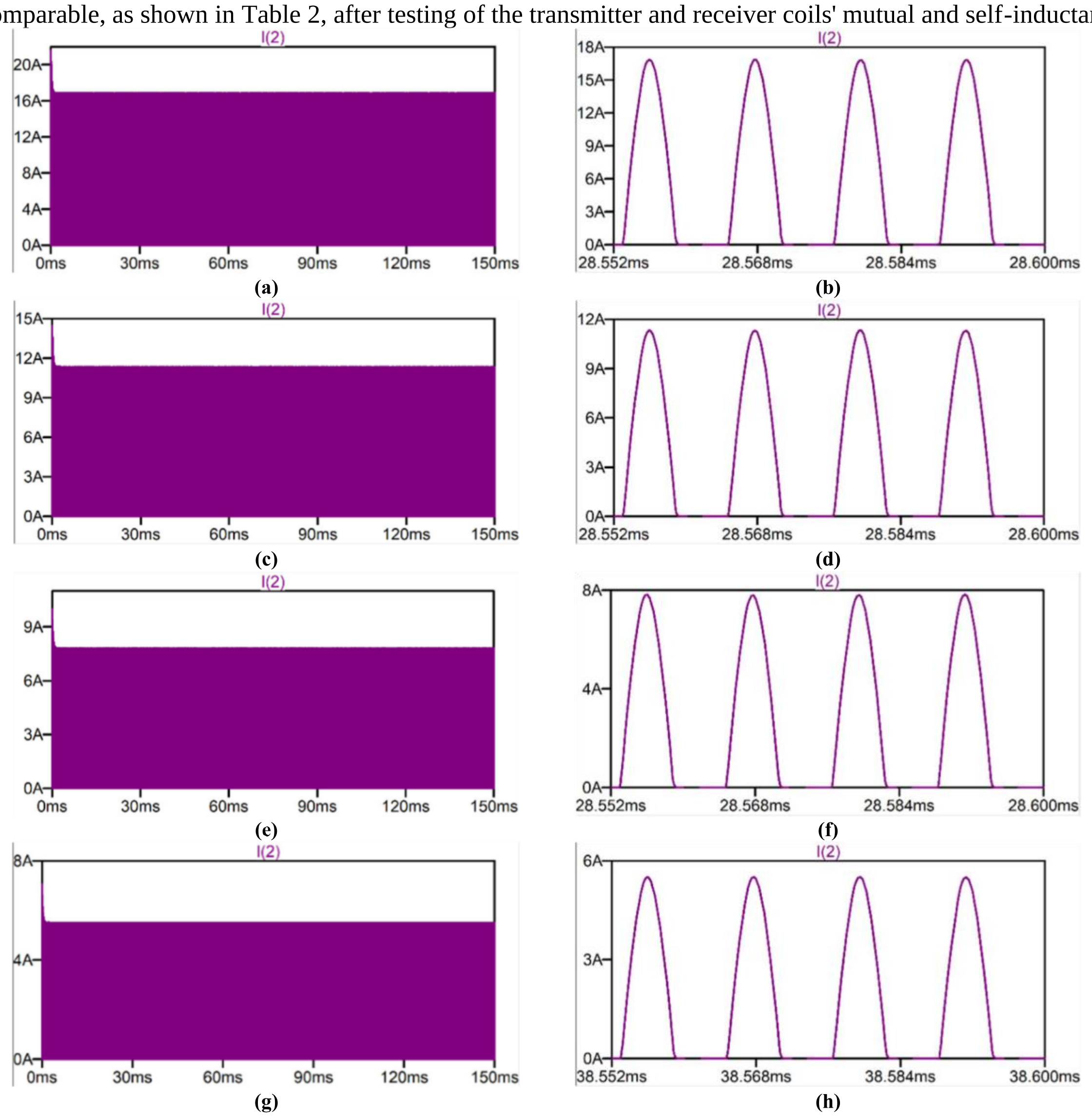


FIGURE 13. Load Current Waveform

TABLE 2.Value of Inductance both Calculated and Simulated.

Inductance	**Calculated**	**Simulated**
Self Inductance(L_1)	176.624 μH	169.844 μH
Mutual Inductance(M)	38.892 μH	37.33368 μH

The mutual inductance and coupling coefficient for a 150mm–300mm air gap between the transmitter and receiving coils are graphically shown in Figure 10. According to this graph, the mutual inductance and coupling coefficient decrease as the air gap grows. As seen in Fig. 11, the mutual inductance is at its maximum magnitude when there is no movement. Whether on the positive or negative axis, the mutual inductance decreases as the displacement increases until it reaches zero at around 350 mm from the centre. This happens when both the x- and y-axes are shifted.

Figure 12 displays the waveform of an input current of 70A with a resonance frequency of 85 kHz. In Figure 13, the load current for the four simulated air gap values is shown. It demonstrates the current's dwindling as it moves from the power transfer coil to the load. These numbers are computed using a model of the circuit shown in Figure 4 with known mutual and self-inductance.

3.74 kW is the load power for the air gap of 150 mm. Table 3 provides additional values for different air gaps between the coils of the transmitter and receiver. As a result, it may take 1 hour and 39 minutes to fully charge the battery of an EV with 6.1 kW of power from a totally discharged condition for a 150mm air gap when the EV is correctly orientated to its transmitting pad. Figure 14 demonstrates that the efficiency of 150mm coils is much greater and rapidly decreases when the air gap between the coils increases [10]–[15].

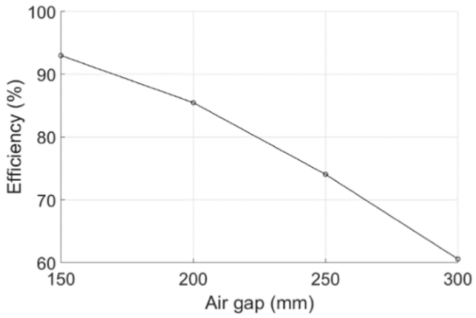


FIGURE 14. Efficiency

TABLE 3. Calculated the Load Power.

Air Gap (mm)	**Load Power (kW)**
150	3.740
200	1.564
250	0.745
300	0.370

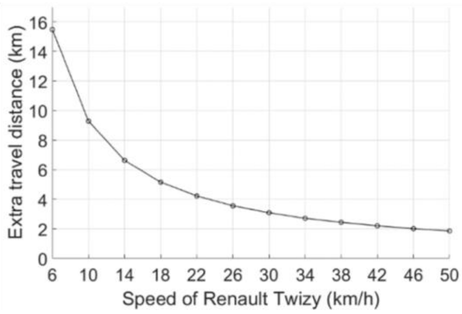


FIGURE 15. Extra Travel Distance

We may determine the power transmission to the receiving end while the EV is moving down a track with no y-axis movement and a 150 mm air gap by inserting the result from Equation (18) into equation (17).

The preceding result shows that power diminishes as the horizontal displacement and air gap change. Figure 15 illustrates how far the extra energy stored in the battery may go via the 150 mm air gap of the Renault Twizy EV to the transmitter coil of the charging lane. It makes sense that the power used is dependent on the EV's speed given the same air gap and no y-axis displacement.

6. CONCLUSION

In recent years, WPT researches have gained in popularity. In this work, the existing WPT techniques are evaluated and contrasted, and RIPT is designed as a substitute. Using the RIPT technique, frequency resonance between the transmitter and receiver coils is established. The impact of air gaps and misalignments on the WPT is shown while an EV is driven through the charging lane. Beginning with a simulation of the effects of the air gap and horizontal movement between the coils on mutual inductance along the x and y axes, the soft Maxwell 3D modelling application used to investigate WPT is utilised to further understand the WPT. Following that, the results should be verified using mathematical formulas. Equations for current, voltage, and inductance between two objects should be found. We provide the resulting estimates of power consumption and efficiency for a 150 mm air gap. The amount of time required to fully charge an EV's battery may be easily determined using the load power. A model is thus developed to investigate power transfer at different rates and, eventually, the range of the EV given the available power. On the other side, speed affects how much energy the receiver pad can absorb from the transmitter pad. Shielding components like ferrite planners and aluminium plates may be used to increase the amount of power that reaches the receiver. This finding could open up new opportunities for research on high-resonant frequency RIPT-based wireless charging of electric automobiles on tracks.

This study's major objective is to show how to determine wireless power transfer for a moving electric automobile using vertical and horizontal misalignment. For the reader to have a complete picture of dynamic WPT, we additionally create and simulate coil misalignment.

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