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Wireless Charging of Electrical Vehicles while driving

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Abstract : Static wireless charging is becoming popular all over the world to charge the electric vehicle (EV). But an EV cannot go too far with a full charge. It will need more batteries to increase its range. Dynamic wireless charging is introduced to EVs to capitally increase their driving range and get rid of heavy batteries. Some modern EVs are getting off this situation. But with Dynamic WPT the need of plug-in charge and static WPT will be removed gradually, and the total run of an EV can be limitless. If we charge an EV while it is driven, we do not need to stop or think for charging it again. Eventually, in the future the batteries can be also removed from EVs by applying this method in everywhere. Wireless charging needs two kinds of coils named the transmitter coil and the receiver coil. The receiver coil will collect power from the transmitter coil while going over it in the means of mutual induction. But the variation of distance between two adjacent coils affects the wireless power transfer (WPT). To see the variation in WPT, a system of two Archimedean coils of copper is designed and simulated for vertical and horizontal misalignment in Ansys Maxwell simulation software. The transfer power for 150 mm air gap is 3.74 kW and transfer efficiency are gained up to 92.4%. The charging time is around 1 hour and 39 minutes to fully charge its battery from 0 state for a 150mm air gap for an EV with 6.1 kW power may take. Also, a charging lane is designed for dynamic charging. Then the power transfer is calculated from mutual inductance when the EV is driven on a charging lane. From the load power, it can be calculated how further an EV can go with this extra power.

Keywords: ***Electric vehicle, wireless power transfer, dynamic charging, efficiency, charging lane.***

I. INTRODUCTION

Electric Vehicles have started their journey when General Motors made the world's first electric vehicle during 1996. But, with the initiation of Chevrolet and Nissan, manufacturers of EV have started a magnificent journey through the technology, and the acceptance of users for it causes no harm to the environment. Also, stepping into EV is considered as to take a significant step towards protecting the environment, enhancing transportation durability, and diminishing fuel dependency. With this great advantage, many automobile manufacturers have started to make immense investments to bring improvement in the technology of the electric automobile. Wireless Charging System (WCS) is working on the theory of Mutual induction is a phenomenon introduced by Sir Nikola Tesla in 1887 where an induced emf is caused in the second coil known as receiver coil can create electrical energy with a given current in the first coil known as transmitter coil.

The current development in this sector by the automobile companies and the research institutes show that within the next ten to twenty years charge while driving (CWD) infrastructure can be stationed for widespread use. That is why many companies have been looking at ways to not only extend the range of EVs by wireless charging but also to make the charging process seamlessly automatic.

II. WIRELESS POWER TRANSFER

A. WPT system

In a generic WPT system for EV, high-frequency ac power is supplied in the transmitter end transfer the power to the receiver end over a specified distance. As RIPT is the most effective WPT for EV so, it is discussed here briefly and the whole structure is designed based on RIPT.

B. RESONANT INDUCTIVE POWER TRANSFER

IPT method can transfer power by the inductive coil. It is the most efficient process for WPT in the static method where the receiver coil is in the centered position over the transmitter coil. But if we think of dynamic charging then the receiver coil is movable as shown in Fig. 1 and can barely collect the magnetic flux from the transmitter coil. Hence a capacitor is used on the transmitter side and as well as on the receiver side known as a compensation network to resonant the transmitter coil and the receiver coil. This method is called the RIPT method. RIPT method is the most efficient - among all technologies to transfer power wirelessly in short-range.

C. CHARGING METHOD

Low-frequency ac power from the grid is converted into a high frequency (hf) ac through ac-dc converter and dc-ac inverter. To ensure maximum power transfer to the receiving end, s-s compensation topology is used in the transmitter coil and the receiver coil. The transmitting pad is typically mounted beneath the surface of the road and the receiving pad is mounted underneath the vehicle.

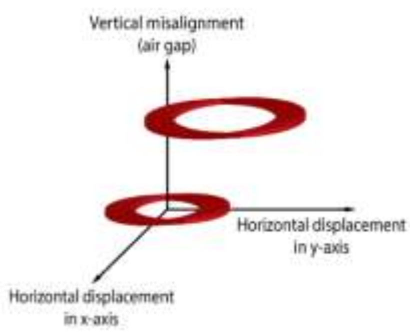

FIGURE 1. Transmitter coil and receiver coil

The receiver pad is usually mounted lower from the frame of the EV to help to catch more magnetic flux.
The high-frequency AC is then converted into DC by using an AC/DC converter and sent to the battery bank. The battery management system (BMS) communications and power controller are used to ensure stable operation and avoid any safety issues. The whole process of charging method from grid to vehicle (G2V)

D. EQUIVALENT CIRCUIT DIAGRAM

In this work, 70A current is used because there is no abrupt voltage drop in the resonance case until the input current is 70A [26]. Also, the increase in input current will increase the overall efficiency. The resonant frequency is set to 85 kHz. An equivalent circuit diagram for the RIPT system is shown in Fig. 3. In the receiver end, an AC/DC is converter is used to convert the high-frequency ac to dc output. C1 and

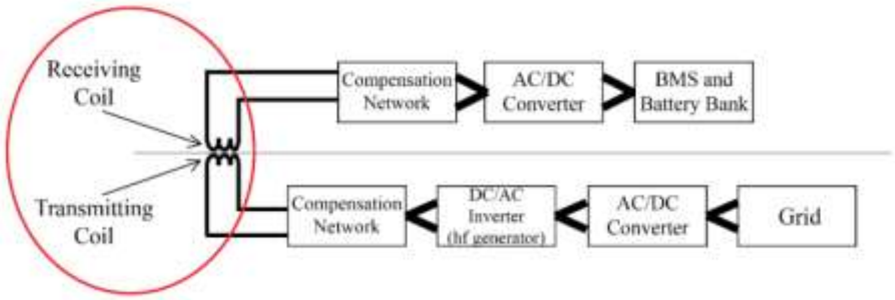

FIGURE 2. Block diagram of grid-to-vehicle (G2V) wireless charging system for an EV

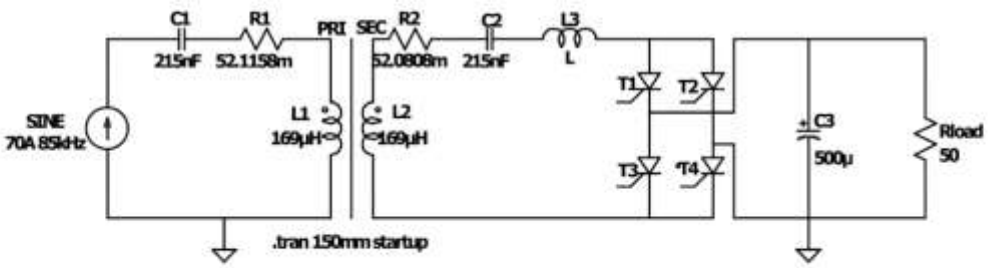

Figure 3. Circuit representation for RIPT system.

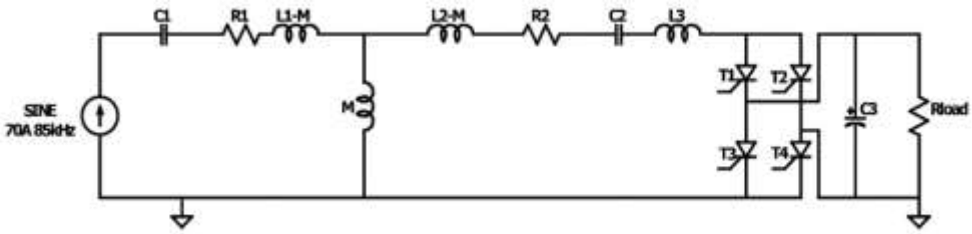

Figure 4. Equivalent circuit diagram for given self-inductance and mutual inductance.

C2 are resonant capacitors of transmitting pad and receiving pad respectively. The circuit simulation is done in LTspice circuit simulation software. In this software, direct mutual induction representation is not possible. So, an equivalent circuit diagram is drawn in Fig. 4 and hence simulated for the load current.

III. COIL DESIGN

TRANSMITTER COIL AND RECEIVER COIL:

There are different shapes of coil used in WPT systems. Among them, the circular coil is the most effective structure in high-frequency wireless transfers as there are no sharp edges. So, the eddy current is kept to minimum. The high magnetic field produced by the coil causes better.

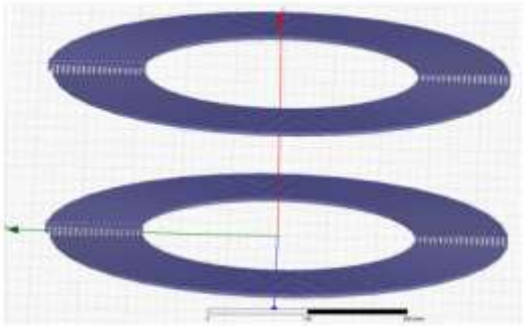

Figure 5. Transmitter and Receiver coil

Name	Transmitter coil	Receiver coil
Number of Turns	18	18
Inner coil radius	140 mm	140 mm
Outer coil radius	232.5 mm	232.5 mm
Radius change	5.3 mm	5.3 mm
Radius of conductor	2.34 mm	2.34 mm
Pitch	0	0

TABLE 1. Specification of the transmitter coil and the receiver coil.

Specification of the transmitter coil and the receiver coil. performance in the WPT system. The proposed transmitter coil and the receiver coil are shown in Fig. 5.

A. COIL SPECIFICATIONS

Many parameters affect the performance of circular coil such as outer radius, inner radius, pitch, number of turns, the radius of conductor [29]. The parameter set for the transmitter coil and the receiver coil is shown in Table 1. In this work, the size of both coils is the same.

IV. RESULTS AND DISCUSSIONS

After the mutual induction simulation, the simulated data of Fig. 9 is generated which is showing the variation of magnetic flux with the increase in the air gap. The region for the magnetic flux density of the transmitter coil is getting smaller with an increase in distance between the coils. As a result, the region for magnetic flux density which receives the receiver also getting smaller. After measuring the self-inductance and mutual inductance of the transmitter coil and the receiver coil it is found that the calculated value and the simulated value are almost the same which showed Table 2.

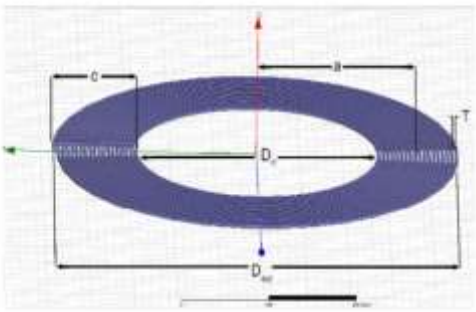

Figure 6. 3D representation of an Archimedean

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

Table 2. Calculated value and simulated value of the self-Induction of the transmission coil and the mutual induction for 150mm air gap.

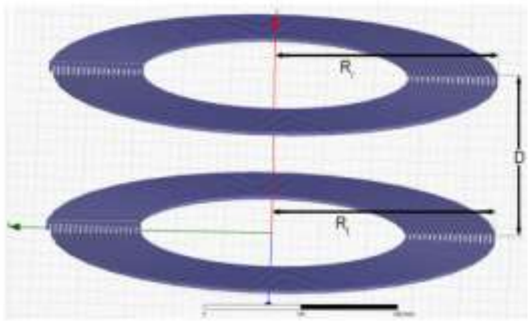

Figure 7. Transmitter and receiver coil at a displacement 'D'

Figure 10 shows the graphical representation of mutual inductance and coupling coefficient for 150mm-300mm air gap between the transmitter coil and the receiver coil. It can be easily seen from this figure that mutual inductance and coupling coefficient is decreasing with the increase in air gap. From Fig. 11, it can be seen that the mutual inductance is in peak value when there is no displacement. But, with the increase in displacement whether in positive or negative axis the mutual inductance decreases and becomes zero at approximately 350 mm displacement from the center. It occurs for both x-axis and y-axis displacement. Fig. 12 shows the waveform of 70A input current with 85 kHz resonant frequency. And Fig. 13 shows the load current for the simulated four values of the air gap. It shows how current will decrease through the power transfer coil and load. These values are obtained by simulating the circuit of Fig. 4 for given self-inductance and mutual inductance. The load power for the 150 mm air gap is 3.74 kW. And other respective values are shown in Table 3 for

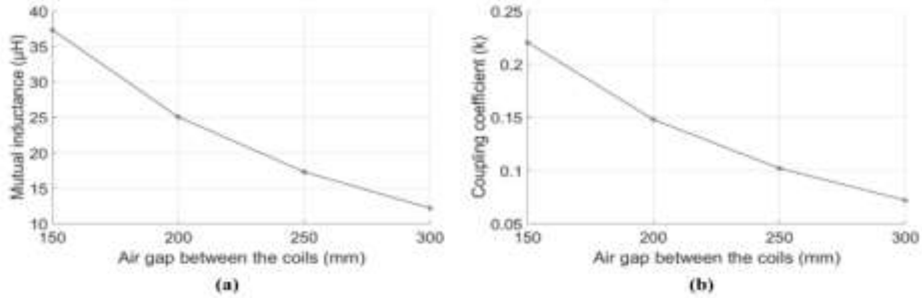

Figure 10. **Reduction of (a) Mutual induction and (b) coupling coefficient with the increase in the air gap.**

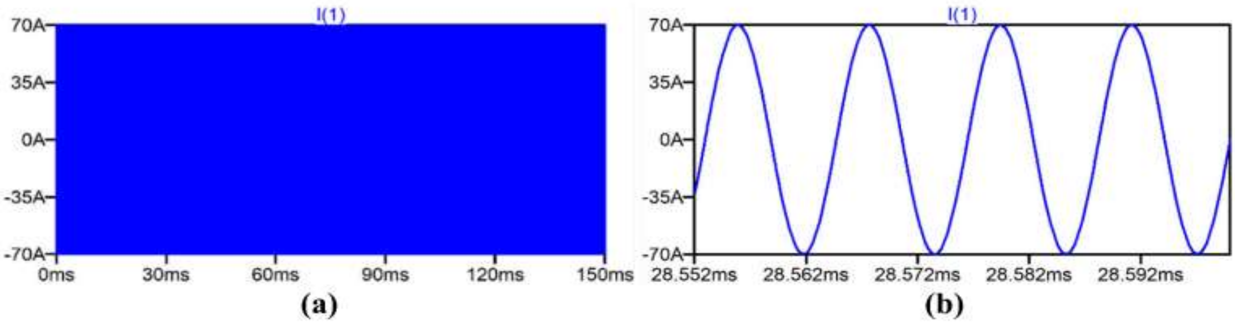

FIGURE 12. **(a) The waveform of input current, I_1 and (b) Large scale view of input current, I_1.**

different air gap between transmitter coil and receiver coil. Therefore, the EV with 6.1 kW power may take 1 hour and 39 minutes to fully charge its battery from 0 state for a 150mm air gap if it is fully aligned to its transmitting pad. Fig. 14 shows the efficiency is much higher for 150mm and abruptly decreasing with the increase of air gap between the coils.

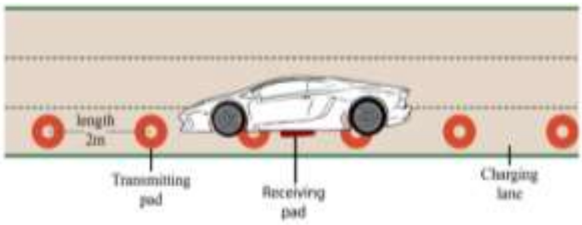

Figure 8. **Scenario layout of the position of transmitting pad for dynamic charging**

V. CONCLUSION

Research on WPT is getting popular these years. This work compares the most famous WPT technologies and develops an effective one known RIPT. The RIPT method is used for resonating the transmitter coil frequency and receiver coil frequency. It shows how air gap and misalignment affect the WPT while the EV is driven in the charging lane. Firstly, WPT is simulated in the Ansoft Maxwell 3D simulation software to see the reduction in mutual inductance for air gap and horizontal displacement between the coils in x-axis and y-axis. Then verify the output data using mathematical equations. Equations for self-inductance, mutual inductance, coupling coefficient, voltage, and current are discussed here. The calculation for load power and efficiency for the 150mm air gap is shown. From the load power, the time for the full charge of the battery of an EV can be easily determined. Hence, a model is established to see the power transfer for different speeds and finally how far the EV can go with this consumed power. But, how efficiently the receiver pad can catch the power from the transmitter pad is also depends on the speed of the EV. Shielding materials like ferrite planner and aluminum plates can be used to transfer more power to the receiving end. This work helps to understand the wireless charging of EVs in the track for high resonant frequency in the means of RIPT and can be extended for future work in this field. The main purpose of this work is to show the calculation of wireless power transfer of an EV while it is in motion based on vertical and horizontal misalignment. Misalignment of coils are also designed and simulated for getting a clear and broad knowledge about dynamic WPT.

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