Modeling and Development of Wireless Power Transmission System for Electric Vehicles

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Abstract: The main objective of this paper is to develop a sustainable Wireless power transmission (WPT) model. WPT is the technique of transferring electric energy from a power source to a load without any contact between them. This process can be done through different methods using different topologies, which include Series Series (SS), Series Parallel (SP), Parallel Series (PS), and Parallel Parallel (PP). One of the most widely used methods in WPT is inductive power transfer. The main advantages of WPT – it allows charging for multiple devices, has high charging speeds, low cost, less maintenance, and higher efficiency than wired charging. Despite significant advancements in charging solutions, the system still has various issues, such as coil position, the number of receiving coils, the distance between transmitter and receiver coils, high initial cost, and impacts on its sustainability. This paper discusses the simulation model of the WPT model using SS topology in the JMAG software and analyzes the effect of the position of coils and distance between transmitter and receiver coils on the output. This simulation model can further be used to build a prototype for charging EV batteries.

1 Introduction

Wireless power transmission (WPT) transfers electric energy from a source to a load without physical connectors or cables. It allows for power transfer over short or long distances without a direct electrical connection. The concept of sustainable WPT has been around for a long time, but technological advances have made it more practical and efficient [1]. The basic principle behind WPT is using electromagnetic fields to transfer energy. This can be achieved through different processes like electromagnetic induction, and resonant coupling. WPT has several benefits; it eliminates the need for physical connectors and cables, reduces clutter, and simplifies the charging process. It also provides convenience and flexibility, charging devices without direct contact [5].

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Additionally, WPT can be implemented in various environments, including homes, offices, public spaces, and even electric vehicle charging stations. However, there are also challenges associated with WPT. The efficiency of power transfer is one of the main issues. Another issue is safety, as the technology has to operate by stringent guidelines to ensure that electromagnetic radiation poses no health risks. Despite these challenges, WPT has gained significant attention and development recently. It has been used in various sectors, including automotive, healthcare, industrial automation, and consumer electronics [1]. Research and development in sustainable wireless power transmission (WPT) have the potential to revolutionize the way we power and charge our electronic devices, paving the way for a more convenient and wire-free future.

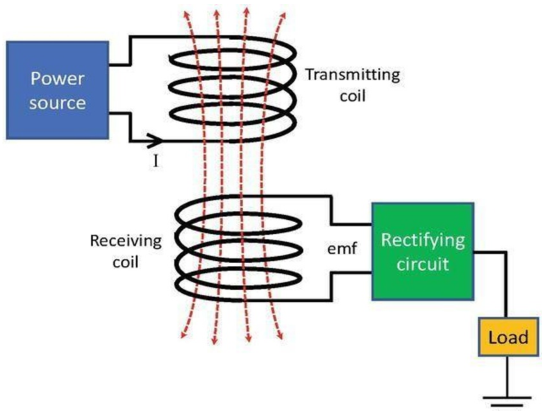

Fig 1. Wireless Power Transmission

2 Wireless Power Transmission

2.1 Block Diagram of Wireless Power Transmission

The wireless power transmission block diagram generally comprises the following components, with a corresponding illustration in Fig 2 [4].

2.1.1 Components of Wireless Power Transmission

Power Source: The power source generates electrical energy that will be transmitted wirelessly. This can be a power grid, a generator, or a renewable energy source like solar panels. *Power Conversion:* The electrical energy from the power source is converted into a suitable form for wireless transmission. *Transmitter:* The transmitter coil creates an electromagnetic field to transfer electricity to the receiver. *Receiver:* The receiver coil receives the electromagnetic field and converts the received energy into a suitable form for the load. *Load:* It is the device or system that consumes the transmitted power. It can be any electrical device, such as smartphones, laptops, or EV batteries.

https://doi.org/10.1051/e3sconf/202343001007

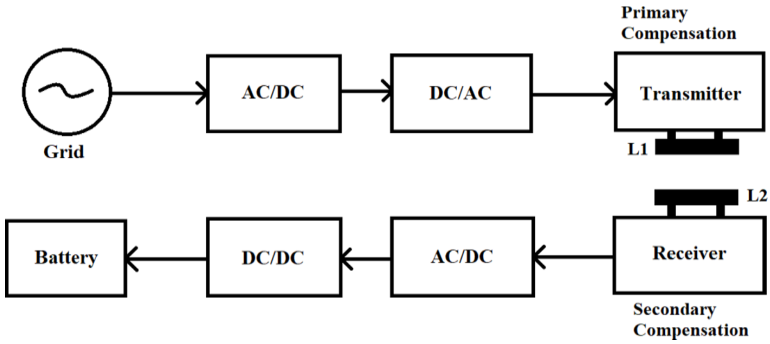

Fig 2. Block diagram of Wireless Power Transmission

2.2 Topologies of Wireless Power Transmission

2.2.1 Circuit Diagram

Topology is the term that refers to the arrangement of components in the circuit. WPT can be arranged using four different topologies- SS, SP, PS, and PP. In this project, SS and SP topologies are used to perform the simulation of the sustainable WPT model [1][10]. The connections between the SS and SP topologies are displayed in Fig. 3 below. In the SS topology, the primary and secondary inductors are connected in series with the capacitor. In the SP configuration, a capacitor is connected in series with the primary inductor, while another is connected in parallel with the secondary inductor [2]. These circuit designs are intended to cancel out the reactive components of the transferred power, hence increasing power transfer efficiency. The design of the primary and secondary circuits (using inductors and capacitors) aims to enhance power transfer. This is done by using less apparent power from the source, ensuring that active power is effectively transmitted to the load, making everything operate successfully [9].

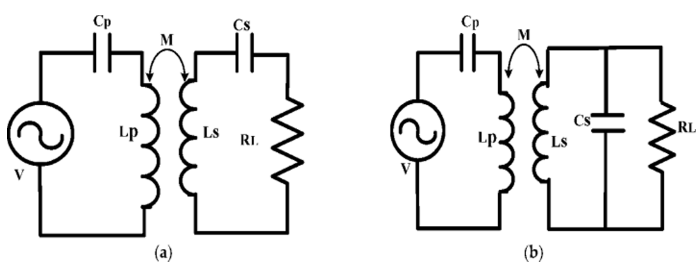

Fig 3. Circuit Topologies (a) SS type (b) SP type

2.2.2 Operation

When an alternating current (AC) is applied to the primary circuit in the SS configuration, the primary inductor generates a changing magnetic field. This magnetic field induces an alternating voltage across the secondary inductor, facilitating power transfer.

The series capacitors in the SS topology aid in achieving resonance and canceling out reactive power, thereby improving power transfer efficiency. While the SP configuration series capacitor in the primary circuit contributes to resonance, the parallel capacitor in the secondary circuit aids in impedance matching and reactive power compensation [7]. Both topologies are designed to optimize power transfer, improve efficiency, and ensure effective energy transmission in WPT systems.

The below-given equations are used to calculate the primary capacitance, secondary capacitance, and load parameters of SS and SP topologies [1] for sustainable wireless power transmission.

For SS topology:

$$C_P = \frac{1}{\omega^2 L_P} \quad (1)$$

$$C_s = \frac{1}{\omega^2 L_s} \quad (2)$$

$$R_L = \frac{\omega \, Ls}{Q_s} \quad (3)$$

For SP topology:

$$C_P = \frac{1}{\omega^2 \left[L_P - \frac{M^2}{L_s}\right]} \quad (4)$$

$$C_s = \frac{1}{\omega^2 L_s} \quad (5)$$

$$R_L = \omega L_s Q_s \quad (6)$$

Where,

ω=Angular frequency (Hz),
L_p=Primary Inductance (H),
L_s=Secondary Inductance (H),
M=Mutual Inductance (H),
C_p=Primary Capacitance (F),
C_s=Secondary Capacitance (F),
Q_s=Secondary Quality Factor,
R_L=Load (Ohm).

3 Simulation Models of Wireless Power Transmission

3.1 Simulation for Basic Model of WPT

For the simulation of sustainable wireless power transmission, JMAG software is used. In this simulation model, the core, primary, and secondary coils are designed in the geometry window. Then designed model will be interfaced with the circuit in the JMAG designer window. The imported model and circuit of this model are shown in Fig 4. The simulation is performed at seven different positions of the secondary coil from the primary coil. The output results of this model are shown in Fig 5.

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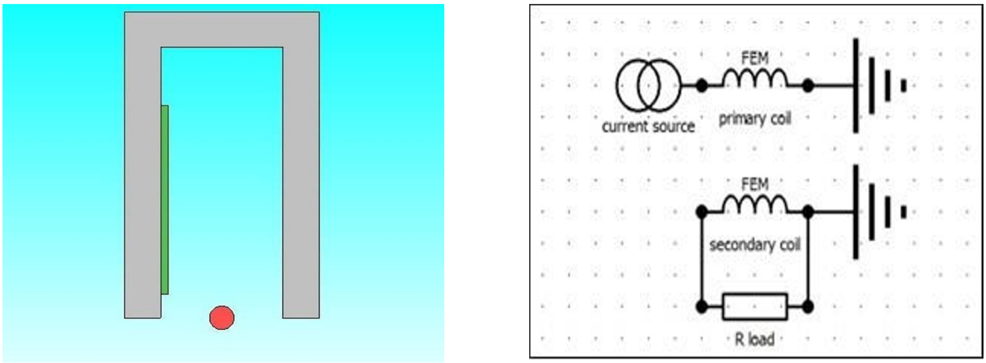
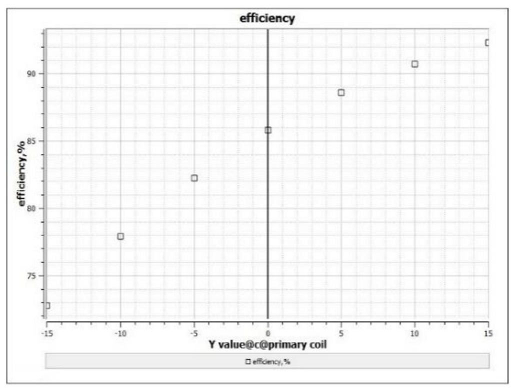


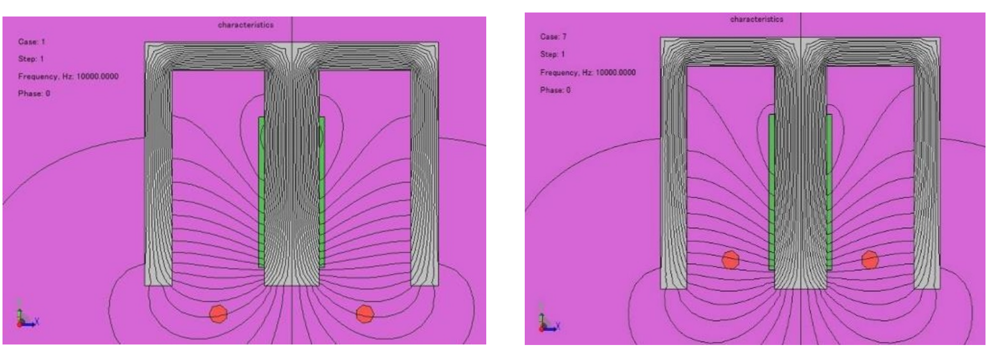
(a) (b)

Fig 4. (a) Imported model & (b) Circuit of the basic model of WPT

	value@c@primary c	efficiency,%
1	-15	72.7901965053
2	-10	77.9224696249
3	-5	82.2721323624
4	0	85.818870866
5	5	88.5996169134
6	10	90.7118382882
7	15	92.3030309616



(a) (b)

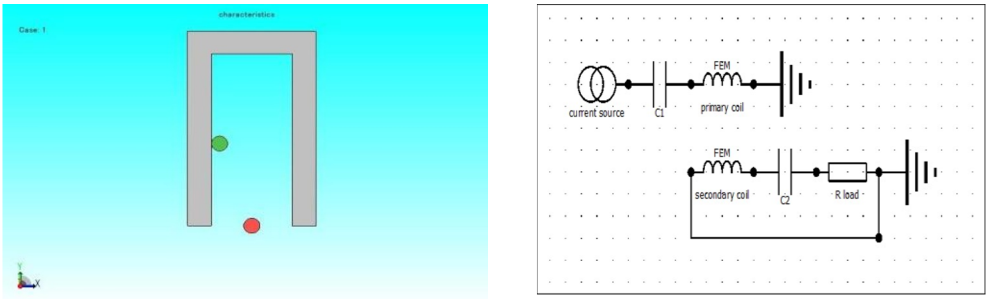


(c) (d)

Fig 5. (a) Efficiency table, (b) Efficiency graph, (c) Flux path at case 1, (d) Flux path at case 7 for the basic model of WPT

3.2 Simulation of WPT using SS topology

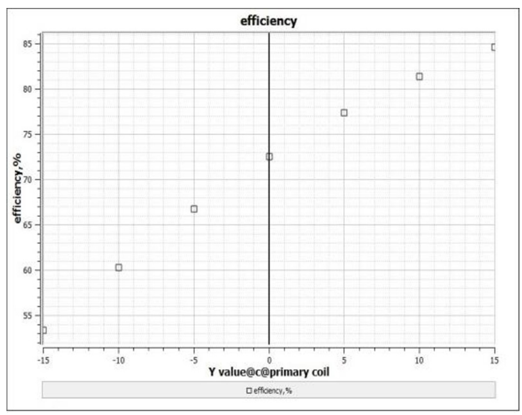
In this simulation model, the SS topology circuit is used to interface with the imported model in the JMAG designer. The imported model and circuit are shown in Fig 6. Furthermore, the output results of this model are shown in Fig 7.



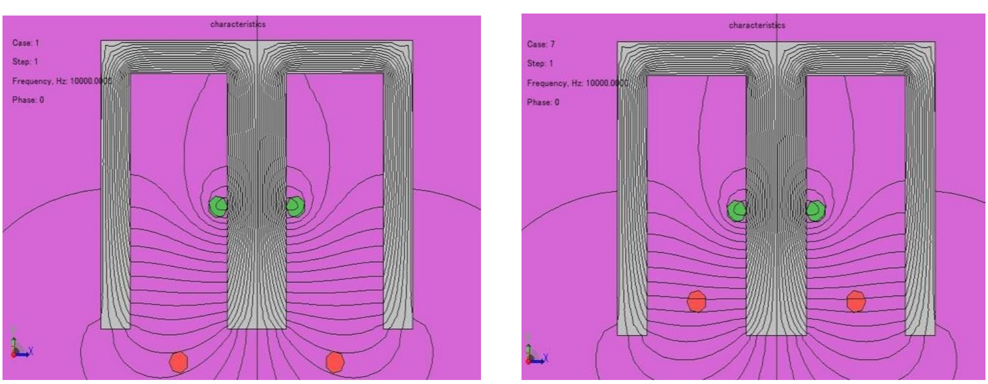
(a) (b)

Fig 6. (a) Imported model, (b) Circuit of WPT using SS topology

	value@c@primary c	efficiency,%
1	-15	53.4356446028
2	-10	60.3202540306
3	-5	66.7687406309
4	0	72.5205855024
5	5	77.3912870863
6	10	81.3950095875
7	15	84.5795361923



(a) (b)



(c) (d)

Fig 7. (a) Efficiency table, (b) Efficiency graph, (c) Flux path at case 1, (d) Flux path at case 7 of WPT using SS topology

4 Conclusion

The simulation model of the proposed method is developed using JMAG software for the basic model of WPT using SS topology. The output efficiency and flux path for both simulation models were observed. Furthermore, when the simulation results of the SS topology model and PS topology model are compared, the results are better in the SS topology than the PS topology. Through this study, it was observed that efficiency improved as the distance between the primary and secondary coils decreased, whereas efficiency decreased when the distance was increased. Moreover, according to the research, SS topology is preferable for sustainable wireless power transmission.

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