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# Wireless Charging System for Electric Vehicles

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**ABSTRACT:**

*Wireless power transmission (WPT) is popular and gaining technology finding its application in various fields. The power is transferred from a source to an electrical load without the need of interconnections. WPT is useful to power electrical devices where physical wiring is not possible or inconvenient. The technology uses the principle of mutual inductance. One of the future applications finds in automotive sector especially in Electric Vehicles. This paper deals with research and development of wireless charging systems for Electric vehicles using wireless transmission. The main goal is to transmit power using resonance coupling and to build the charging systems. The systems deal with an AC source, transmission coil, reception coil, converter and electric load which are battery.*

**KEYWORDS:**

*Wireless power transfer; Resonance; Inductance; Electric vehicles; High frequency converters*

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## 1. Introduction

Mankind has been using automotive vehicles for transportation from one place to another. These vehicles use internal combustion(IC) engines to drive it. Due to increased number of vehicles there is environmental pollution caused by IC engines and reduction in fossil fuels. The latest innovations in the Automotive Industry are helping to improve fuel efficiency and reduce emissions. One such technological advancement is Hybrid vehicles which use both IC engines and electric motors to drive the vehicles or a car in simple words, helping to reduce the amount of emissions produced maintaining the performance of the engine. However, in the future, the focus is on clean and green energy producing zero emissions. Design and manufacture of electric vehicles has led to major interest in current industry [1]. Since these vehicles run on battery the main drawbacks are high cost, short distance travel and long charging time. Consumers are constantly looking for a better solution to improve the travel efficiency. Hence wired charging systems were built at every gas station.

Wired charging also have some limitations like socket points, spacing occupied by the charging station, limited range of wire, vehicle has to change its orientation to connect to the charger. These can be addressed by wireless charging systems for electric vehicles. This provides flexible and hassle free charging and also systems can be built at home, parking lot, garage etc. Fig. 1 shows simplified diagram of car and wireless charging system implemented in automotive industry [2]. Many wireless power transfer techniques are used to implement this technology. These methods use coils to transmit power. Coil will produce a short range magnetic field, when a second coil is placed an electric current will flow through it. The magnetic field has transferred power from one coil to other called Induction. It is necessary to analyze these techniques based on the application to obtain optimum results for the system to function correctly. Table 1 shows different techniques with its advantages and disadvantages [3] [4].

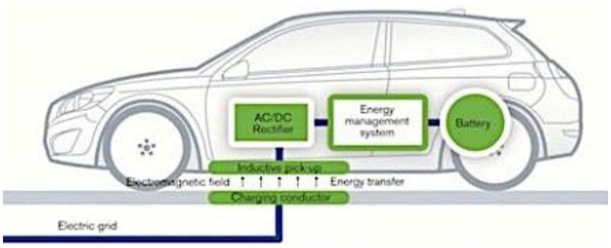


**Fig. 1: Prototype of wireless charging system**

**Table 1: Wireless power transfer techniques**

| Techniques | Advantages | Disadvantages |
|---|---|---|
| Inductive coupling | Simple, safe and high transfer efficiency in short distance. | Short transmission distance needs accurate alignment. |
| Magnetic resonance coupling | Long transmission distance, no radiation. | Difficult to adjust resonant frequency for multiple devices. |
| Electromagnetic radiation | Very high transmission efficiency over a long distance. | Produces radiation, needs a line of sight. |

This work uses resonant coupling methods to achieve efficient power transmission. The system is configured at the reasonable air gap based on the ground clearance of electric vehicle. This air gap is enough to provide good amount of coupling coefficient. The design of coils plays major role, factors like geometry, frequency and coil placement to deliver the maximum power with a uniform field distribution.

## 2. Wireless charging system architecture

The system shown in Fig. 2 gives an overview consisting of various components for charging to take place.AC supply is used as the source which is supplied to high frequency(HF) converter which converts source low frequency to high frequency. This output is fed to the transmission coil (TX). From the principle of resonant coupling the reception coil (RX) is coupled. The output is given to AC-DC converter to obtain rectified DC to charge the battery which the load. The coils in the project which is used to transmit power wirelessly are called magnetic resonators. Firstly, a rapidly oscillating current is fed to a coil at a specific resonant frequency using HF Converter. This creates magnetic field in the region around a transmission coil, tune a reception coil to the same resonant frequency as the source it will couple resonating anywhere within that region, converting oscillating magnetic field into an electrical current within the reception coil this response is called coupled magnetic response. The power can be fed to the load for charging a battery. This power can be distributed across multiple loads.

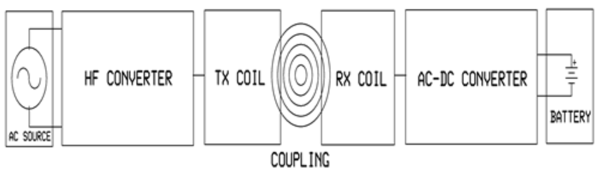


**Fig. 2: Block diagram of wireless charging system**

The basic circuit model of the WPT system is shown in Fig. 3 connected in series to series topology [5]. Considering the complexity of the system it's easy to analyze the simplified equivalent network model. The circuit consists of primary and secondary winding $L_1$ and $L_2$ respectively. $R_1$, $C_1$ connected at primary side and $R_2$, $C_2$ at secondary side. These components are linear and passive in nature. The RLC circuit exhibits a property of resonance. The values of LC can be adjusted in such way so as to obtain a resonant frequency of 10 kHz to 30 kHz. The current through the primary coil $I_1$ is determined by input voltage $V_1$, and by the total impedance of the secondary coil as seen by the primary coil. The total impedance of the circuit is given by,

$$Z_1 = R_1 + j\left(\omega L_1 - \frac{1}{\omega C_1}\right)$$

$$Z_2 = R_2 + R_L + j\left(\omega L_2 - \frac{1}{\omega C_2}\right) \quad (1)$$

$$C_1 = \frac{1}{\omega_0^2 L_1} \text{ and } C_2 = \frac{1}{\omega_0^2 L_2} \quad (2)$$

$$0 \leq k \leq 1 \text{ and } k = \frac{M}{\sqrt{(L_1 L_2)}} \quad (3)$$

The through current can be kept constant in amplitude if input voltage is varied as a function of R1, which would result in induced voltage in secondary, which is denoted by M in Fig. 3 called mutual inductance, where $M=L_{12}=L_{21}$. The series to series topology behaves like a constant current source producing constant output current. In order to obtain the resonant frequency with a fixed inductance of coils capacitance C1 and C2 can be calculated by Eqn. (2).Mutual Inductance M is further dependent on the distance and position of the primary and secondary coils. The ratio of the mutual inductance M and square root of self inductances L1 and L2 is termed as coupling coefficient k, shown in Eqn. (3).

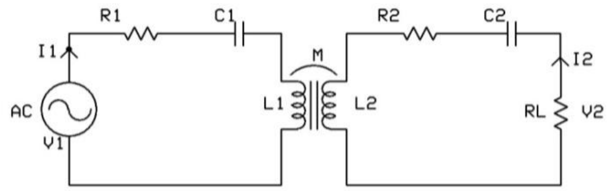


Fig. 4: Circuit model for series to series topology

## 3. Design of transmission & reception coils

Wireless power systems use magnetic cores to improve the magnetic flux density and current running through a closed loop creates magnetic flux density denoted as B. This loop encloses a surface S through this magnetic flux Φ. Eqn. (4) and Fig. 4 explain the concept [5]. Placing second closed loop within the surrounding of the first loop, due to the magnetic flux density B the second loop will have a mutual flux $\Phi_{12}$ as given by,

$$\Phi B = \int S B dS \quad (4)$$

Magnetic flux density B is proportional to applied current I. In order to run a current in closed loop coil is used. If the coil has N turns each turn will have magnetic flux density B i.e. $B \propto NI$. So when we consider two coils or closed loops with N1 and N2 turns magnetic flux between both the coils give mutual inductance. The inductance of the coils is determined by factors like geometry, coil alignment and permeability of the medium as follows,

$$M = \frac{\mu_0 \mu_r N_1 N_2}{l} \quad (5)$$

$$L = \frac{d^2 * N^2}{18d + 40l} \quad (6)$$

Where $\mu_0$ defines permeability constant measures amount of resistance exhibited to form magnetic field in vacuum $\mu_0 = 4\pi \times 10^{-7}$ H·m$^{-1}$. $\mu_r$ relative permeability defines ability of conductor in magnetic field. A is the area of cross-section the conductor. *l* is the length of the conductor or coil. Similarly, the values of the self inductance L of the coils can be calculated using the Eqn. (6). Where *d* is the diameter of cross-section [5]. All the above can be implemented in simulation tools to analyze the working of the coils in 2D and 3D space.

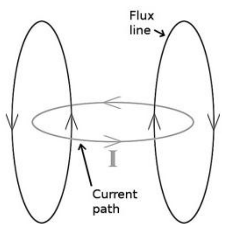


**Fig. 4: Loops and magnetic flux Φ**

## 4. 2-Dimensional analysis

Finite Element Magnetics Method (FEMM) an open source tool that helps in 2-D analysis of planar problems in the conductor in which components like heat, current, magnetics can be studied. Results such as self and mutual inductance, resistance can be extracted. Fig. 5 shows a 2-D placement of primary and secondary coils having 20 turns each with a minimum air gap of 20 cm for a uniform field distribution to obtain optimum inductance [5]. This design is intended to be used in series to series topology producing constant output current. Table 2 displays the extracted values after the simulation.

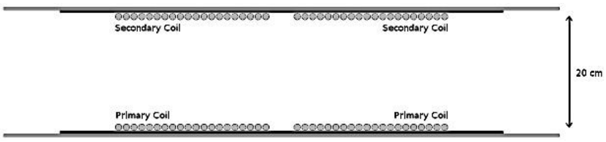


**Fig. 6: 2-D Visualization of the coils**

**Table 2: Simulated results from 2-D FEMM**

| Geometry specifications | Values | Simulated results | Values |
|---|---|---|---|
| Primary coil turns | 20 | Primary coil inductance | 167 µH |
| Secondary coil turns | 20 | Secondary coil inductance | 167 µH |
| Coil radius | 30 mm | Mutual inductance | 50.6 µH |
| Core radius | 1.2 mm | Primary coil resistance | 21.5 mΩ |
| Air gap | 20 cm | Secondary coil resistance | 21.5 mΩ |

## 5. 3-Dimensional analysis

ANSYS Maxwell is the electromagnetic field analysis software that uses finite element method. It is a powerful tool to study the complex 3-D model of coils in space similar to real world environment [7]. The design was performed on ANSYS Maxwell v16.0 at Circuit Simulation and PCB fabrication Lab, TIFAC CORE, VIT University. The flexible drawing tool helped us to design geometry of coils in 3-D space. The reception coil is replicated from transmission coil since both the self inductance have fixed to tune at resonating frequency. Fig.6 depicts the transmission coil and reception coil placed one above the other within the air gap of 10 cm to obtain maximum field distribution enclosed in an air box which acts as transfer medium.

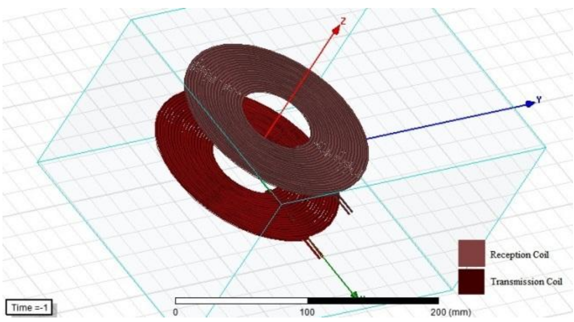


**Fig. 6: 3-D visualization of the coils enclosed in an air box**

The material of the coils is set to copper. The air box medium is chosen as air. Material of the conductor and air decides the $\mu_r$ relative permeability. The static magnetic analysis can calculate self and mutual inductances of a coil. Analysis needs to be performed to determine magnetic coupling between the two coils as a function of the spatial location with respect to each other. The terminals of transmission coil are excited with current. The flow of current in a coil exhibits magnetic field which is coupled with reception. Post analysis we obtain the fields distributed across the coils within the air box. This data is helpful to understand the coupling and design of coils in real time. Figs.7 (a) and (b) show the plots of 2-D and 3-D field distribution respectively. The excitation to the coils in Maxwell is given in passive method. In order to realize an active external HF converters are necessary to excite the coils to resonant frequency.

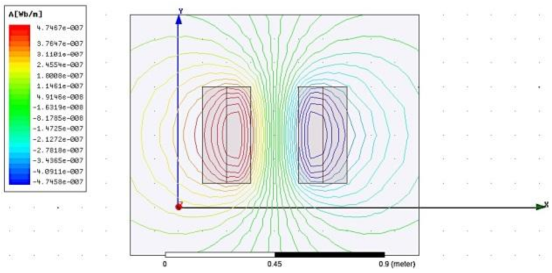


**Fig. 7(a): 2-D field distribution**

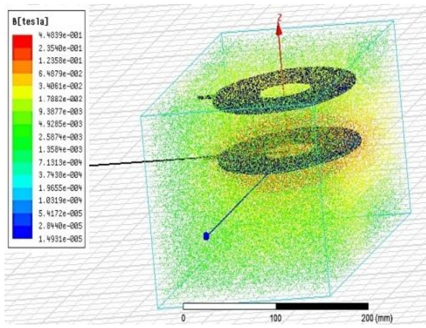


**Fig. 7(b): 3-D field distribution**

## 6. Design of converters

Design of a power supply systems in wireless charging system plays a crucial role. The major challenge was to obtain High frequency in terms of kHz and output power $P_{out}$ of 1 kW to excite the coils and charge the load respectively [8]. HF converters in transmission side and AC-DC converters in reception side were realized on MATLAB Simulink. In real time we used the same high current capacity diodes 1N5406 used in HF converter. Fig. 8 shows the circuit diagram of converter system [9].

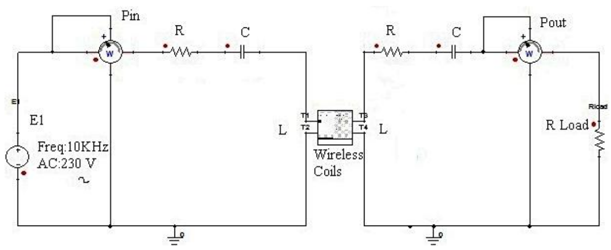


**Fig. 8: Time scope values of HF converter; Input voltage & current = 230V & 5A, Output voltage & current = 200V & 10A**

## 7. ANSYS Simplorer co-simulation

All the systems analyzed individually and obtained optimum results. In order to understand the functioning of overall system, we used a powerful tool called ANSYS Simplorer. This tool helped us to accurately design the complex wireless charging control systems

[7]. The Wireless coils were imported from Maxwell and integrated within Simplorer circuit with the help of equivalent active and passive components. The values of RLC were chosen for resonant frequency. L is the fixed value of coils inductance co-simulated from Maxwell. Post analysis input power (Pin) and output power (Pout) were calculated with different RLC combinations, shown in Table 3. These experimental results supported us to a build a prototype of the wireless charging system for electric vehicles.

**Table 3: Simplorer co-simulation results**

| Transmission Side | | | Pin | Reception Side | | | Pout |
|---|---|---|---|---|---|---|---|
| R(Ω) | L(H) | C(F) | (W) | R(Ω) | L(H) | C(F) | (W) |
| 1m | 167µ | 1.5µ | 1 k | 0.5m | 167µ | 100µ | 800 |
| 1m | 167µ | 1.5µ | 2 k | 0.5m | 167µ | 5.5µ | 900 |
| 7.2m | 167µ | 1.5µ | 3 k | 3.6m | 167µ | 5.5µ | 1 k |

## 8. Conclusion

In this work, design and analytical experiments were performed for wireless power transmission and charging system. We accurately designed all the models for individual system and co-simulated in the end. We see that maximum efficiency of the system depends on the resonance and distance between coils to achieve an optimal power transmission. Table 3 gives the input and output of the developed wireless charging system.

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