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Wireless Charging System For Electric Vehicle

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Abstract: *This project is designed to charge a rechargeable battery wirelessly for the purpose. Since charging of our battery is possible to be demonstrated. This project is built upon using an electronic circuit which converts AC 230V 50Hz to AC 12V, High frequency. The output of fed to a tuned coil forming as primary of an air core transformer. The secondary coil here develops a voltage of HF 12volt. Thus the transfer of power is done by the primary (transmitter) to that of secondary is separated with a considerable distance (say 3cm). Therefore the transfer could be seen as the primary transmits and the secondary receives the power to run load. More over the technique can be used in number of applications, like to charge a mobile phone, iPod, laptop battery, propeller clock wirelessly. And also this kind of charging provides a far lower risk of electrical shocks as it would be galvanic ally isolated. This concept is an Emerging Technology, and in future the distance of power transfer can be enhanced as the research across the globe is still going on.*

Key Word*: Wireless power transfer; Resonance; Inductance; Electric vehicles; High frequency converters.*

I. Introduction

It is expected that 500 million electric vehicles (EVs) will be on the roads by year 2030 [1]. The technology and infrastructure for charging of electric vehicles will be the key enabler for this mobility transition. EV charging facilities will be required at homes, workplaces, shops, recreational locations and along highways. The EV charging power has to be provided by the distribution network at quite low cost, with minimal reinforcement and at maximum reliability. Large penetration of EV can lead to increase in the peak demand on the grid and possible overloading of distribution network assets [2], [3]. Secondly, the current electricity grid is mostly powered by fossil fuels like coals and natural gas [4]. When EVs are charged from such a grid, a large part of the emissions are merely moved from the vehicle to the power plant. This makes EVs not truly green as one would expect. Hence it is important for the future that EVs are charged from sustainable sources of electricity like solar or wind [5]–[8]. At the same time, EV can play a decisive role with their ability to act as controllable load and as storage for the grid with fast response. Charging infrastructure for electric vehicles will be the key factor for ensuring a smooth transition to e-mobility. It is here that five technologies will play a vital role in the EV charging infrastructure: smart charging, vehicle-to-grid (V2G) technology, charging of EVs from the photovoltaic panels (PV) contactless charging and on-road charging of EVs. The goal of our paper is to review these five technologies here, provide examples of their implementation and recommendations for the future, through the wireless link. The microcontroller validates and then perform specific task on the device.

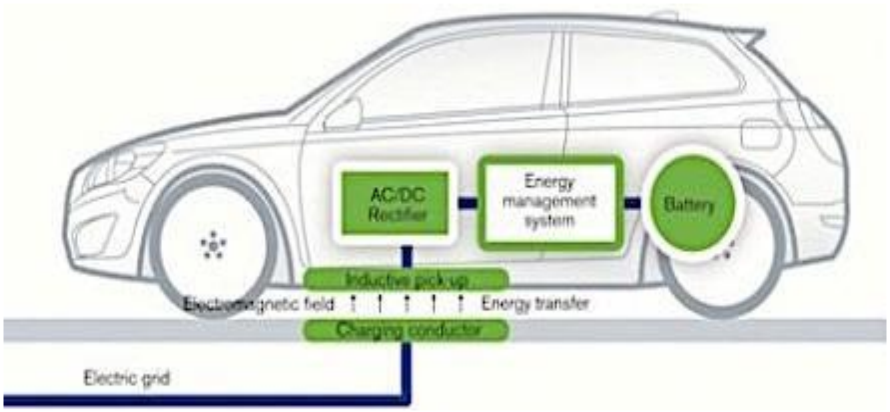

Figure no I Prototype of wireless charging system

Table no I: Wireless power transfer techniques

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

II. Material And Methods

1. Basic wireless charging system architecture

The system shown in Fig. here 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 a 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 coils at a specific resonant frequency using HF Converter. This creates here 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.

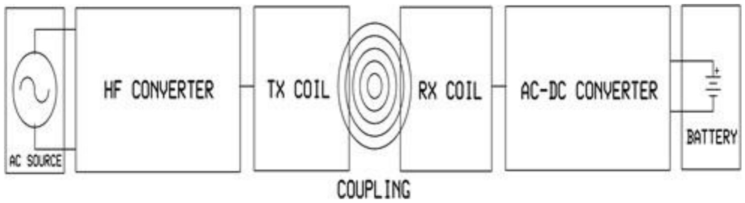

Figure no II. Block diagram of wireless charging system

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 L1 and L2 respectively. R1, C1 connected at primary side and R2, C2 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 that, to obtain a resonant frequency of 10 kHz to 30 kHz. The current through the primary coil I1 is determined by input voltage V1, and by the total impedance of the secondary coil as seen by the primary coil. The total impedance of the circuit is given by,

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

$$Z_2 = R_2 + R_l + j\left(wL_2 - \frac{1}{\omega c_2}\right)(1)$$

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

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

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=L12=L21. 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)

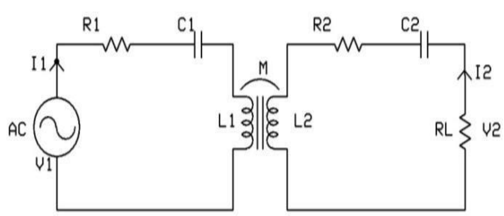

Figure no III Circuit model for series to series topology

2. 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 fluxΦ. 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 Φ12 as given by,

Φ (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∝NI. So when we consider two coils or closed loops with N1 and N2 turns magnetic flux between both the coils give mutual inductances. The inductance of the coils is determined by factors like geometry, coil alignment and permeability of the medium as follows,

$$M = \frac{\mu_0 \mu_1 N_1 N_2}{l} (5)$$

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

Where μ0 defines permeability constant measures amount of resistance exhibited to form magnetic field in vacuum μ0= 4π × 10−7 H·m−1. μr 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 here 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.

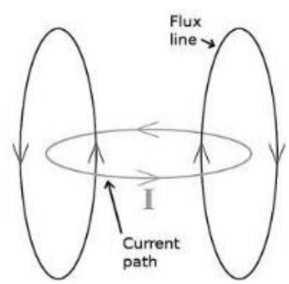

Figure no IV Loops and magnetic flux

3. Design of converters

Design of a power supply systems in wireless charging system plays a crucial role. The major challenge for us was to obtain High frequency in terms of kHz and output power Pout 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].

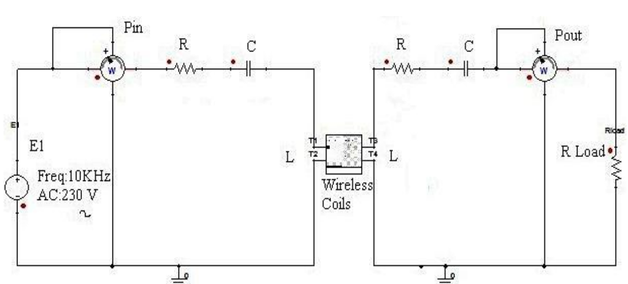

Figure no V Time scope values of HF converter; Input voltage & current = 230V & 5A, Output voltage & current = 200V & 10A

III. Result

1. 2-Dimensional analysis

Finite Element Magnetics Method (FEMM) an open-source tool that helps us in 2-D analysis of planar problems in the conductor in which components like heat, current, magnetic 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.

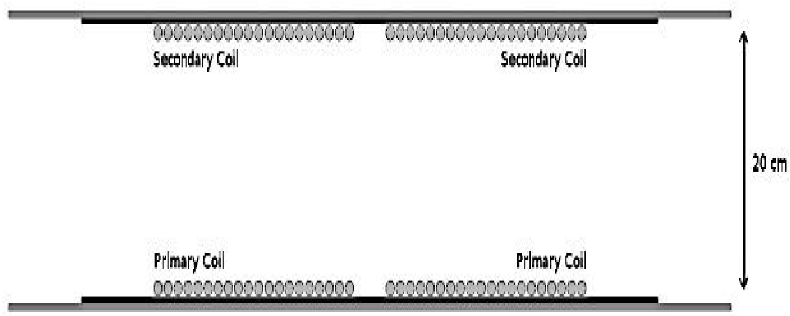

Figure no VI 2-D Visualization of the coils

Table no II- Simulated result from 2-D FEMM

Geometry specifications	Values	Simulated results	Value
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	21.5mΩ

2. 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 tools 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.

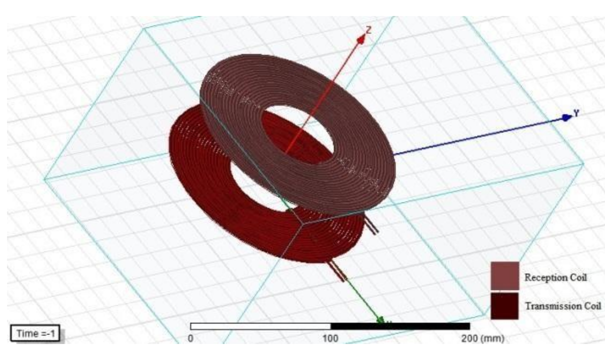

Figure no VII. 3-D visualization of the coils enclosed in an air box

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 μr 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.

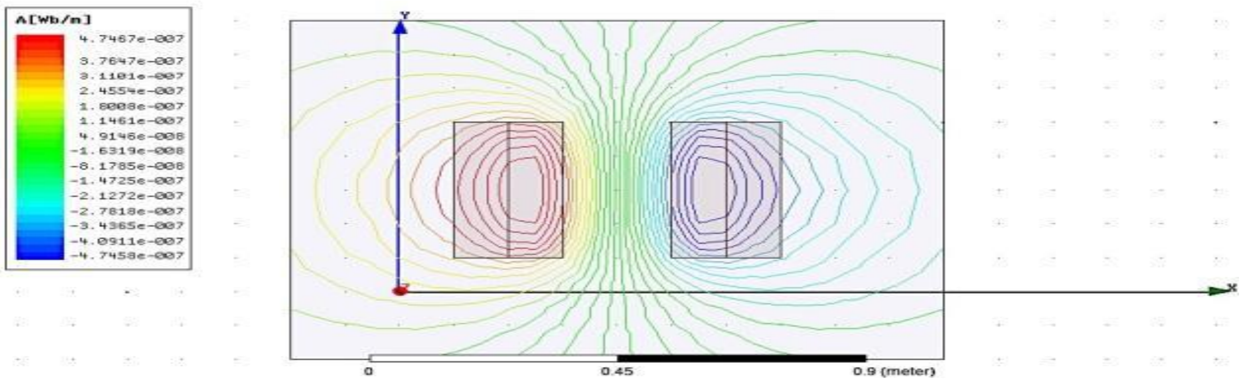

Figure no VIII 2-D field distribution

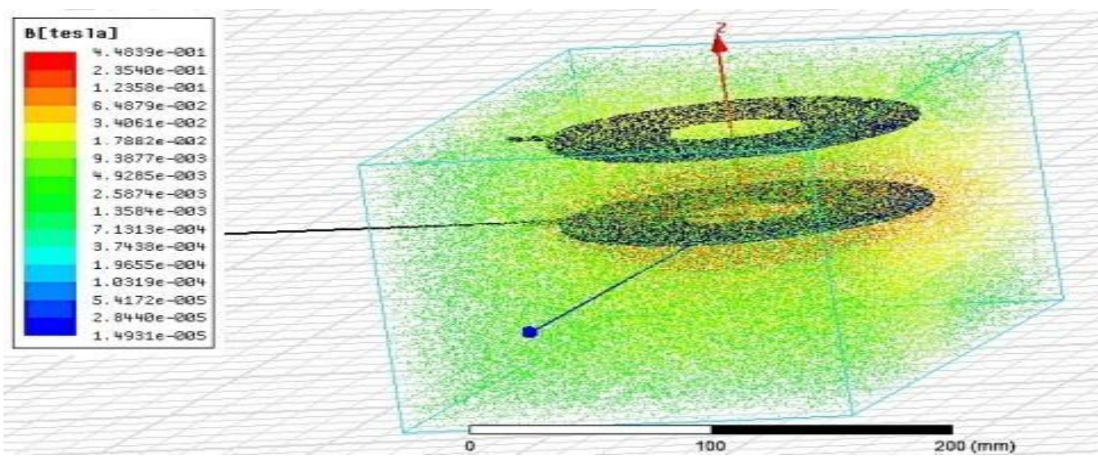

Figure no IX 2-D field distribution

3. 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 Implorer 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 no III: 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

IV. Conclusion

In this paper, wireless charging of electric vehicles was studied. For the primary winding's specifications, the operating frequency, the power transferred and its length are discussed here. The contradictory advantages and disadvantages make it difficult to draw a universal conclusion concerning these parameters. However, an operating frequency of 100 kHz is a realistic value which provides quite high transfer efficiency. The maximum length of the primary winding in such case can be up to 300m. Here significant driving ranges extension and decrease of the battery size of the EV that can be achieved. The road coverage for many scenarios was calculated. For 40% coverage of the road, an EV with a battery of typical size (24kWh) could achieve 500km driving range if the on-road system transfers 25kW. Moreover, the total power requirement for powering all the EVs passing-by was estimated. This micro grid would consist of solar panels, wind turbines and storage placed on the roadside

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