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# Wireless Charger for Electrical Vehicles with Large Air Gap

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***Abstract: In this paper the work has been done to analyze the idea of transmitting power wirelessly to Electric Vehicles. The research depicts a mechanism which has the ability to transfer power wirelessly which will reduce the dependence on foreign oil. Wireless Power Transfer using magnetic resonance is the technology which would set the human free from the hassle of wires. It adopts the basic theory of Inductive Power Transfer. The transferring distance increases from several millimeters to hundred millimeter. This adaptive technique will prove to be a revolutionary change in the field of Electronics.***

***Keywords: Wireless Power Transfer (WPT) System, Principles of Resonant Wireless Power Transfer (WPT), Wireless Charging For Electrical Vehicles.***

## 1. INTRODUCTION

The world for many years has been working for the improvement of energy and transportation sector which will be more favorable and friendly to the environment for this the electrification for transportation has been carried out from trains to privately owned cars.
The Electrical vehicles till now have not been attractive to the consumer because of their drawbacks in charging and their battery design.

For the past decade the world is progressing towards the transfer of power wirelessly and is continuously looking for innovative ideas to charge devices wirelessly. As a consequence the world has extended to the high power applications i.e. for the charging of batteries of Electrical Vehicles, one of the most important reason of such chargers is the improved safety and avoiding of high electrical surges.

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One of the most widely existing Wireless Power Technology relies on the resonance between two specially designed coils, one of which acts as a power transmitter while the other works as the receiver [1, 2]. Resonance is the critical frequency on which the coil accepts the maximum power which is established by the different combination of capacitor with the coil (i.e. series – series, series – parallel, parallel - parallel) this enhances the electromagnetic field to link two loosely coupled coils. The design which the author opted was the parallel – parallel combination of capacitor with coil. The discussed resonance can be achieved by the fast switching components like insulated gate bipolar transistors (IGBTs) or metal oxide semi-conductors field effect transistors (MOSFETS) but to avoid the interference of on board electronic devices the trend is shifted to operate the coil on comparatively low frequencies (<MHz).

**A. Resonance in Wireless Power Transmission**

The concept of transmitting power without using wires i.e. transmitting power as magnetic waves from one place to another in order to reduce the transmission and distribution losses. This concept is known as Resonance Inductive Coupling (RIC)[3].

The distance at which the energy can be transferred is increased if the transmitter and receiver coils are resonating at the same frequency.

This resonant frequency refers to the frequency at which an object naturally vibrates or rings – much like the way a tuning fork rings at a particular frequency and can achieve their maximum amplitude.

**B. Parallel-Parallel Topology**

Parallel-parallel topology is effective technique for wireless power transfer. In this research parallel-parallel topology was used to achieve the resonance based on the results of Table 1. The pictorial representation of P-P topology can be observed in Fig.1.

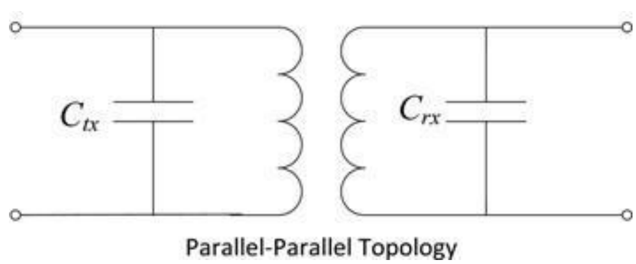


Figure 1: Parallel-Parallel topology for resonance

The results of the table 1 represents PP topology as a promising solution for a high voltage and high – power wireless battery charger [4, 5]. As the table 1 depicts a sensible output voltage and current ratings which will transmit power without stressing the transmitting and receiving circuitry.

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| | PP | SP | SS | PS |
|---|---|---|---|---|
| dc bus input voltage | 150 V | 120 V | 70 V | 200 V |
| battery voltage | 200 V | 200 V | 100 V | 100 V |
| maximum $C_p$ voltage | 165 V | 180 V | 525 V | 220 V |
| H-bridge current peak | 22 A | 37 A | 114 A | 70 A |

Table 1: Output and Input Values depending on Topologies

**Simulation**

**A. Basic circuit**

To accomplish the task of making a Wireless Charger different series of experiments were carried out from which one of the circuit that was implemented is shown in the Fig, 2. The diagram shows the use of parallel-parallel topology Fig. 1.The basic method to achieve the objective of wireless transmission is that to gain the resonance i.e. a frequency. The concept can be elaborated as, when an alternating current is passed through the transmitter coil, to generate magnetic field in the coil which induces a voltage in receiver coil, this can be used to power a mobile device or charge a battery [6].To accomplish this a set of transistors Q1 and Q2 were connected in parallel with 50% duty cycled waveform as an input to their gate. The battery „V1" represents the dc input to the MOSFETs. The secondary coil of this wireless charger is connected to the diode rectifier to charge the battery, whereas the resistance„R1" depicts the internal resistance of the battery and „V2" is the battery that has to be charged.

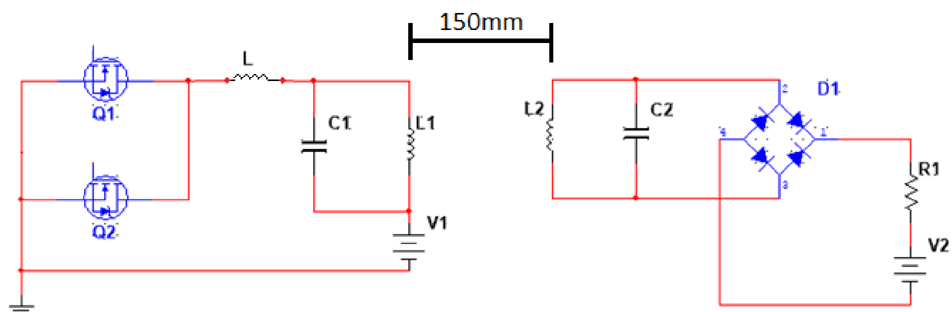


Fig. 2. Wireless charging system

The equivalent circuit of figure 1 is shown in figure 3 where „Lm" is the Mutual Inductance of two coils. „L1" and „L2" arethe inductance of the two coils and „Vs." represents the outputfrom the MOSFETs to the transmitting coil. In this paper two coils are identical thus L1 = L2.

Let us consider that the average Electrical Vehicle that runs onbatteries with the operating voltage at 200V. So, to design a wireless charger the requirements or minimum output requiredto charge a Battery will be around 200 volts and at least 20 A.

 

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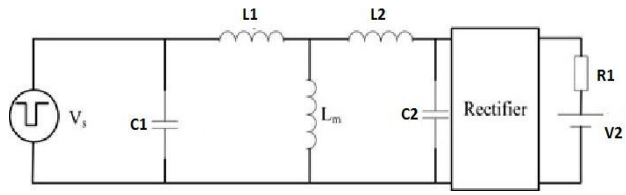


Fig. 3. Equivalent Circuit of the discussed WPT system

**B. Equations**

The whole concept of generating magnetic field and using magnetic lines of forces as a source of connection between the two distant coils relies on the current Thus, the current needed at the secondary coil can be utilized to know the minimum magnetic field needed to pass that much current. Thus we can use the formula to find the magnetic field at the center of air cored solenoid

$$b = \mu * (\frac{N}{}) * i \tag{1}$$

The turns to length ration can be chosen per one‟s own requirement. For preliminary designed coils let us consider 35cm radius with 3 turns and the distance between the transmitting and receiving coil to be 15 cm. The coil gap in Vehicles varies from 100mm to 250 mm depending upon their types and design. This magnetic field can be used to find the input parameters for the transmission coil by utilizing the following equation.

$$I = (\frac{2.b}{u.n}) \times (\frac{D+L}{\sqrt{(D+L)^2+R^2}} - \frac{D+L}{\sqrt{D^2+R^2}})^{-1} \tag{2}$$

Where,
D = distance between the two coilsL = length of the coil
R = radius of the coiln = no. of turns
u = permeability of free spaceI = current in primary coil
b = magnetic field at the center of receiving coil

The above equation will give the current that should be supplied to the primary coil to obtain the specified current at the output. The resistance of the complete circuit shown in figure 3 can be described as follows:

$$Z(\omega) = j\omega L_d + \frac{1}{j\omega C_p} //\{j\omega L_{p1} + j\omega L_m //(j\omega L_{s1} + R1//1/j\omega Cs \tag{3}$$

The above calculation led to the value of primary and secondary inductance as ‟18.23 µH‟ whereas the mutual inductance founds out to be „5.72 µH‟. The actual inductance which plays the role in

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wireless transmission is the leakage inductance and mutual inductance. The leakage inductance is calculated by the use of coupling coefficient described in the given formula comes out to be "12.53 µH" for both primary and secondary coil. The capacitors used in the simulation are „0.86 µF". The parameters are tabulated in table 2. To observe the resonance frequency i.e. the frequency at which we will obtain the maximum output. Figure 4 shows the plot of impedance with respect to the change in frequency.

$$L1p = L \, . \, (1 - k) \qquad (4)$$

$$L1s = L \, . \, (1 - k) \qquad (5)$$

$$k = \frac{L_m}{L_s} = \frac{L_m}{L_p} \qquad (6)$$

Where,

$L1_p$ = leakage inductance of primary coil
$L1\ s$ = leakage inductance of secondary coil
$Lp$ = inductance of primary coil
$Ls$ = inductance of secondary coil
k = coupling coefficient $0 \leq k \geq 1$

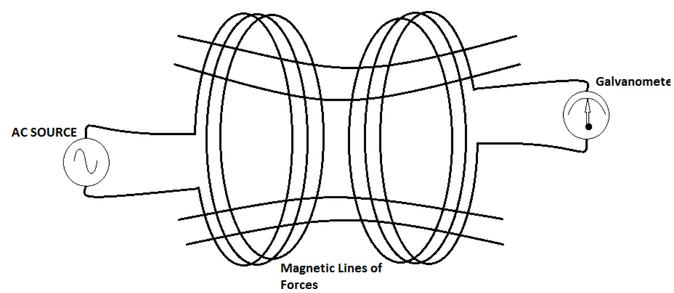


Fig. 4. Coil representation of WPT system

Table 2: Simulated Parameters

| Components | Values |
|---|---|
| Inductance of Receiving Coil | 19.7684µH |
| Inductance of Transmitting Coil | 19.7684 µH |
| Leakage Inductance Lp / L1 | 12.53 µH |
| Leakage Inductance Ls / L2 | 12.53 µH |
| Capacitance of Primary Coil | 0.86 µF |
| Capacitance of Secondary Coil | 0.86 µF |
| L / Ld | 16.8 µH |

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### C. Effect of Change in Inductance of 'L'

The inductance „L" used in the circuit is used to stabilize the current running through the circuit. The removal of this inductance creates a stress on the circuit making it to heat up. Following graphs will show the effect of change in „L" to resonance frequency. The graph shows the effect of inductor „L" placed to improve and stabilize the current input. By graph Fig, 5, we can observe that the impedance of the circuit is increasing with the increase in inductance whereas when we observe the Fig, 6, we can see that the increase in inductance is actually making the circuit to take less current as input. Shown in Fig. 5, Fig, 6. Fig, 7.

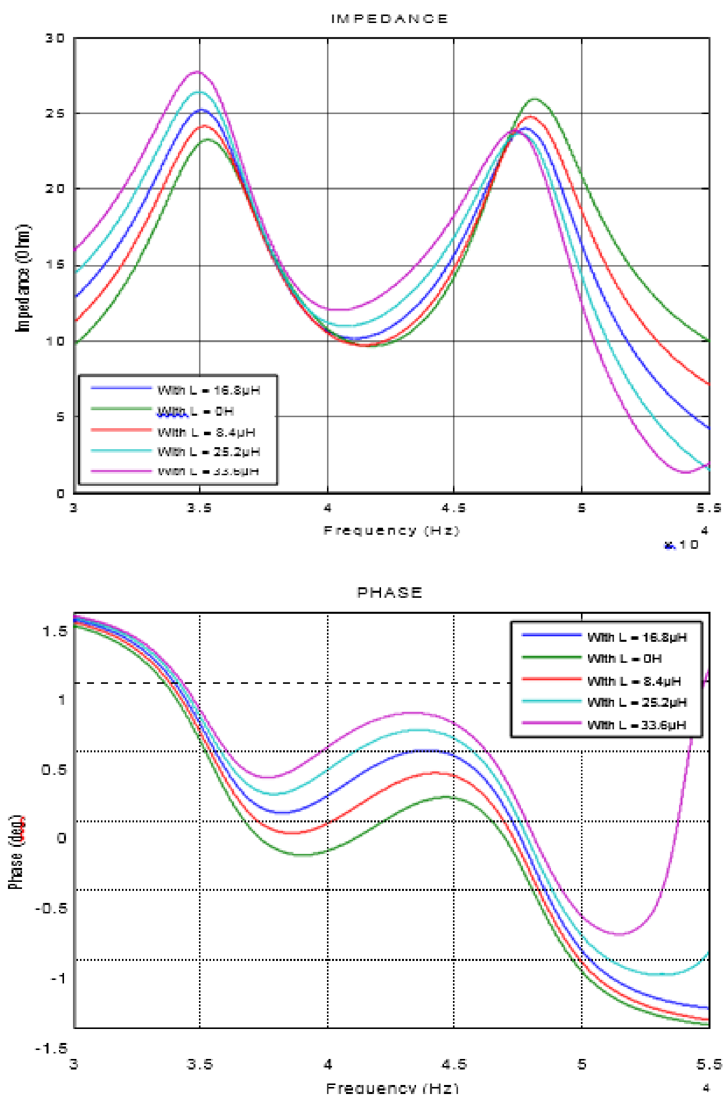


Fig. 5. Effect on Impedance with change in Inductance 'L'

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On a required current we can also observe the input voltage by the following equation and the results can be observed in figure 5 which shows that at 200 volts input at the resonance frequency the current requirement will be "19.75 A" whereas the graph also shows the amount of different current at different impedances. The current which seems a lot is comparatively less as compared to the other topologies which depends on the different combinations of capacitor with inductor (PP = Parallel-Parallel , SP = Series-Parallel, SS = Series-Series, PS= Parallel Series).

$$i_{pp} = v/j\omega L_d + \frac{1}{j\omega C_p} //\{j\omega L_{p1} + j\omega L_m // (j\omega L_{s1} + R1//1/j\omega Cs \quad (7)$$

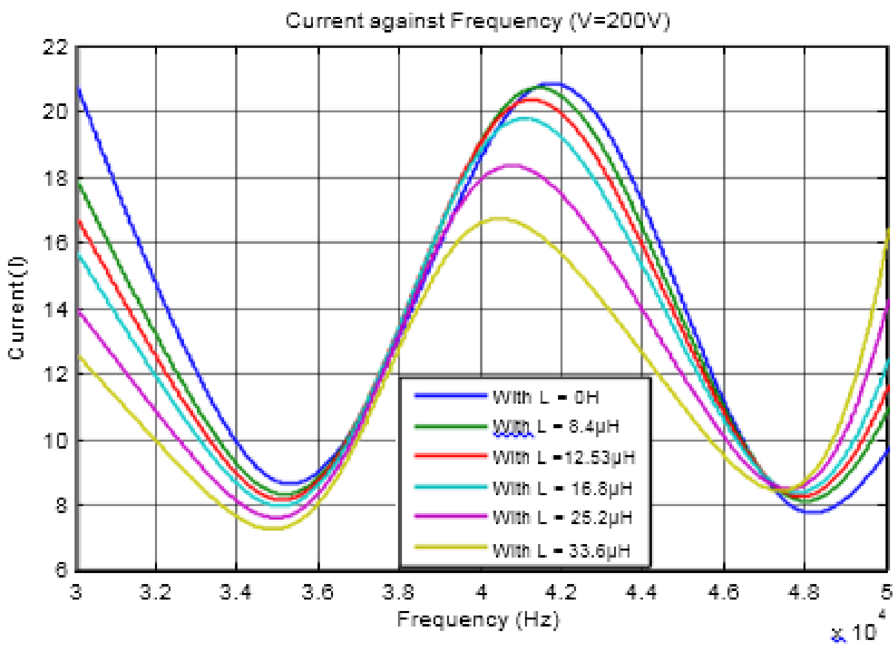


Fig. 6. Change in current with change in frequency

**D. Effects of Change in Capacitance**

Capacitor is one of the main components on which the resonance relies. We can also say that the working of wireless transmission depends upon it. By equation

$$\overline{f_r} = 1/2\pi\sqrt{LC} \quad (8)$$

Following are the graphs which shows the change in resonance frequency with the change in capacitance in Fig, 8.

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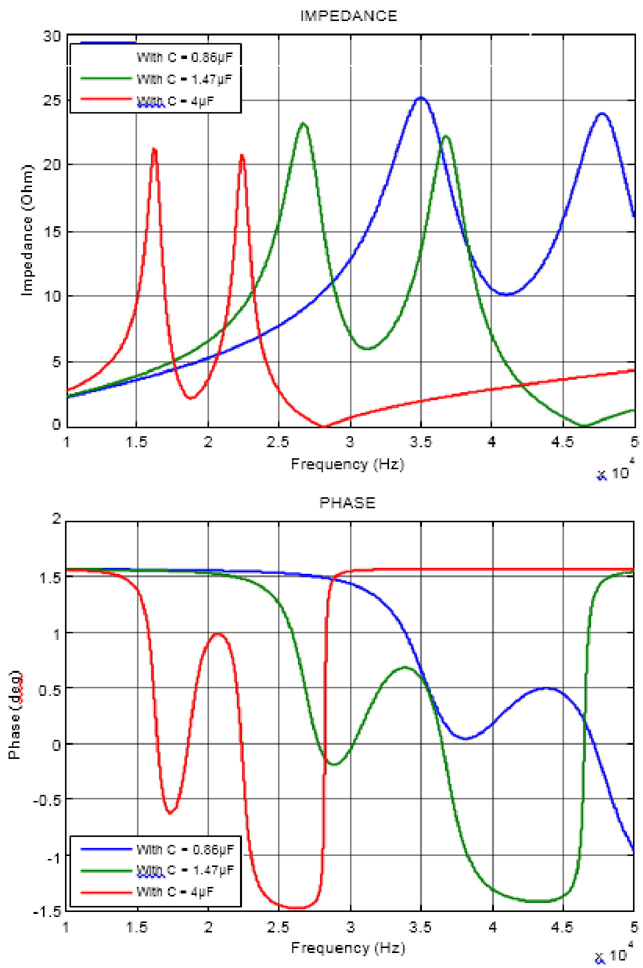


Fig. 7. Effect on Impedance with change in Capacitance

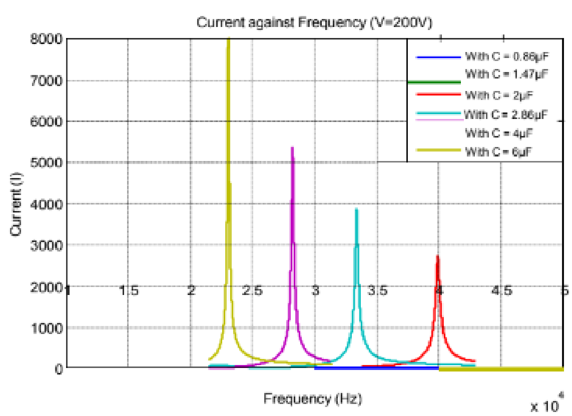


Fig. 8. Change in current with the change in Capacitance

 

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### E. Effect of Change in Mutual Inductance

Mutual inductance actually defines the strong or loose coupling of the two coils. It depends upon the input current as well as the distance between the two coils also affects the mutual inductance. The mutual inductance as well as the leakage inductance varies according to the distance between to the coil whereas the sliding i.e. how much the receiving coil overlaps the transmitting coil will also affect the strength of coupling between the two coils.

The graph states that the increase in mutual inductance is actually lowering the operating frequency as well as the impedance of the circuit. The behavior proves that the change in resonant frequency due to the change in distance affecting the mutual inductance will improve the efficiency of the circuit.

The results of such conditions are tabulated in Fig,11 and Fig, 12 in a graphical manner.

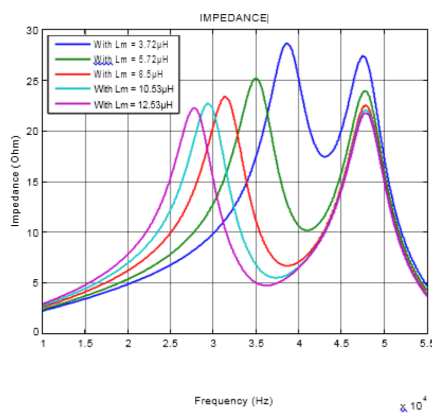


Fig. 9a. Effect on Impedance with change in Mutual Inductance

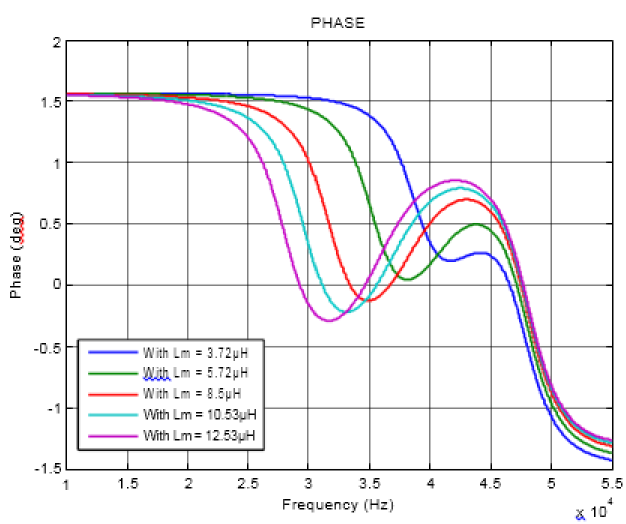


Fig. 9b. Effect on Impedance with change in Mutual Inductance

 

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The current intake of the circuit is increasing with the increase of mutual inductance which may increase the stress on the circuit making it to heat up, represented in Fig, 13.

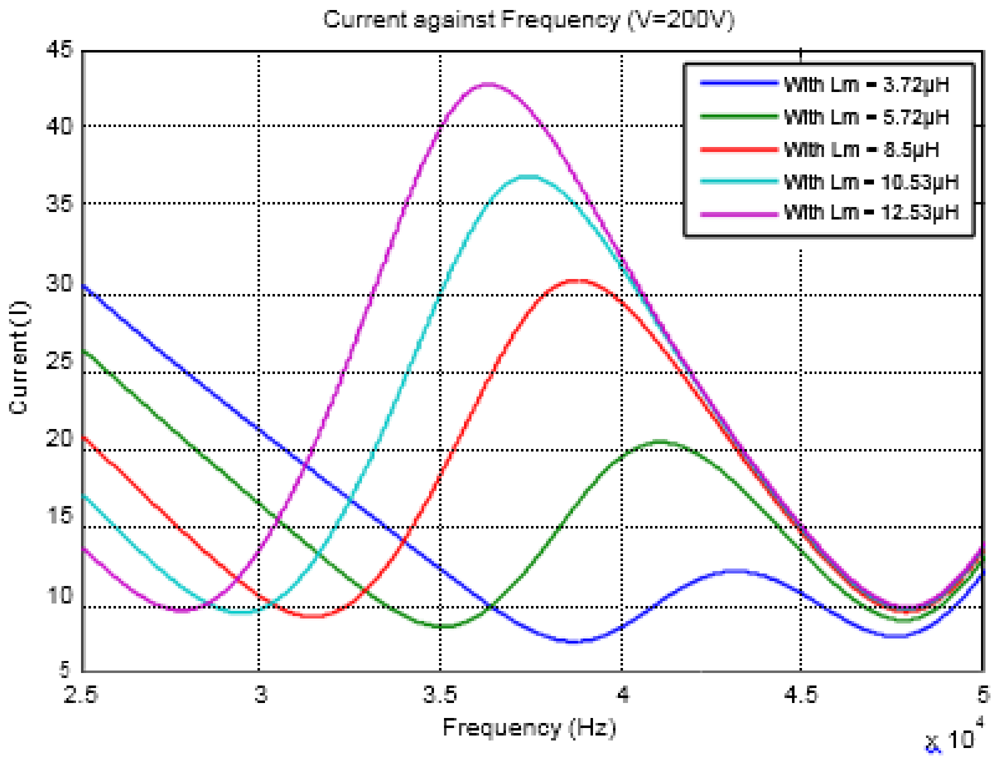


Fig. 10. Effect on Impedance with change in Mutual Inductance

### F. Effect of Shape of Coil

Apart from the quality factor of the inductor, the magnetic coupling „k" defines the efficiency of the power transfer. For maximization of the magnetic coupling „k", an optimized magnetic design of the inductor is of high Importance.

Typical shapes of WPT inductors include circular, square, and Rectangular structures. We used circular shaped inductor coil for placement free system

### Test Bench

The hardware implemented was comparatively capable of less power transfer but followed the same calculations as well as uses the same circuit strategy discussed above. The hardware developed was capable of 5W power transfer to a range of 1millimetres to 10 millimeters with an efficiency of around 83.33%.The results and graphs of the discussed equation are as follows:

 

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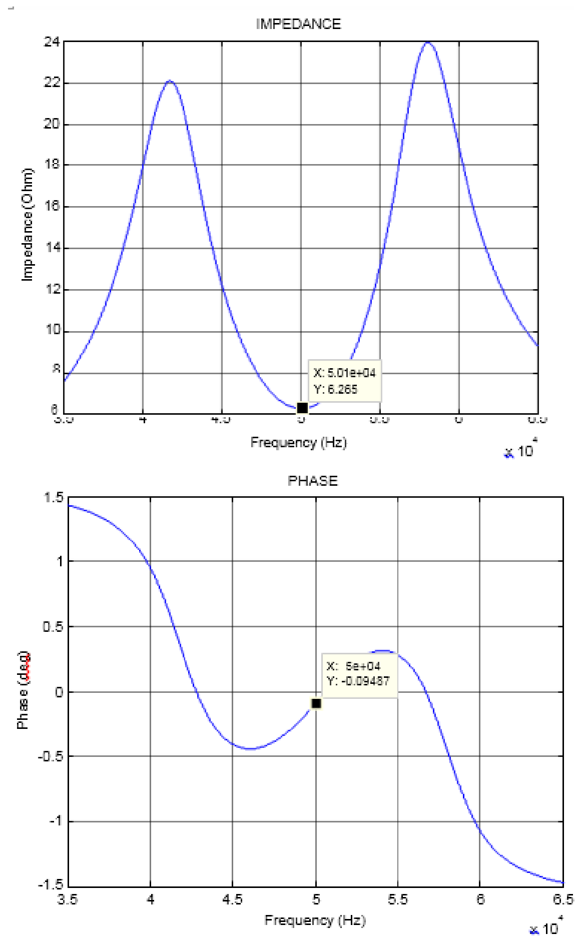


Fig. 10. Graph defining the Resonant Frequency

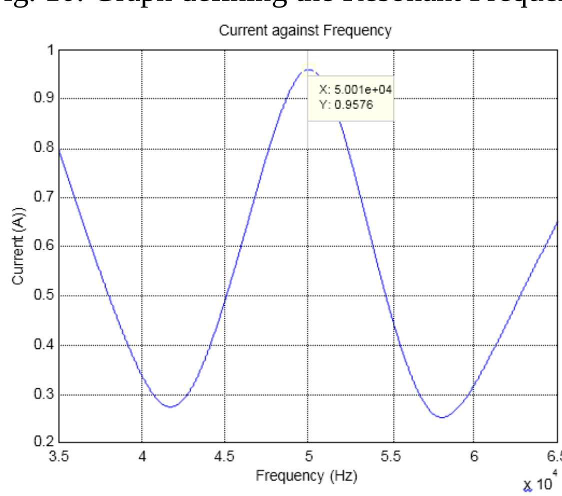


Fig. 11. Graph defining the current requirement at 6V input

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The simulated results of the test bench are as follows which shows the voltage at the transmitting and receiving side.

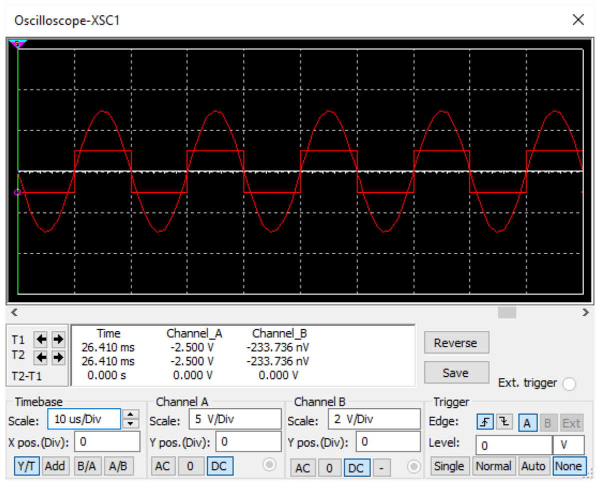

Fig. 12. Output of transmitting side

The above figure shows switching resonant frequency as square wave and the sine wave shows the final voltage at the transmitting coil.

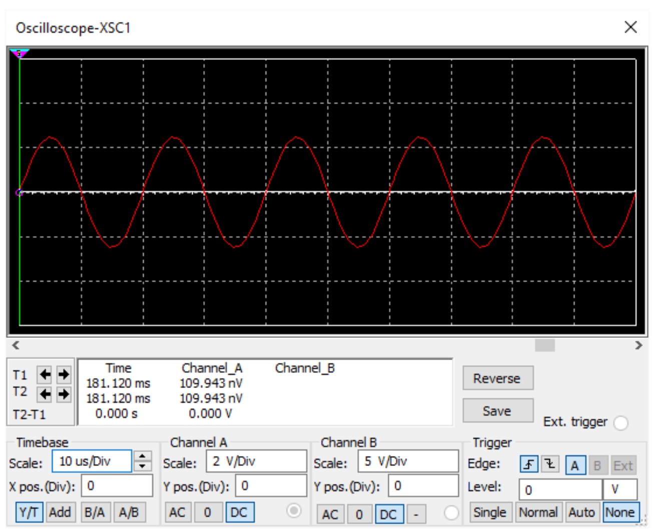

Fig. 13. Input of receiving coil

The above figure 11, shows the input at receiving end which is further processed that is it converts the input into a rectified DC for utilizing it to charge the batteries.
The parameters that have been discussed above and utilized to implement in the development of hardware (test bench) are tabulated in table 3.

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The hardware take 200V AC input rectifies it and utilizes it for transmitting wireless power from the transmission circuit. The circuit utilizes 6V as its input whereas on the input side we were able to gain 5V and 1A. The current and voltage specifications are tabulated in table 4.

Table 3: Parameters of test bench

| **Components** | **Values** |
|---|---|
| Inductance of Receiving Coil | 12.7684µH |
| Inductance of Transmitting Coil | 12.7684 µH |
| Mutual Inductance of Coil | 4.1684 µH |
| Leakage Inductance Lp / L1 | 8.67 µH |
| Leakage Inductance Ls / L2 | 8.67 µH |
| Capacitance of Primary Coil | 0.86 µF |
| Capacitance of Secondary Coil | 0.86 µF |
| L / Ld | 12.8 µH |
| Resonance Frequency | 50 kHz |

Table 4: Voltage and Current of the Test bench

| **Components** | **Voltages (V)** | **Current (A)** |
|---|---|---|
| Cooling Fan | 5 | 0.04 |
| PWM Circuit | 5 | 0.1 |
| Wireless Transmission Circuit | 6 | 1 |
| Charger Output | 5 | 1 |

The test bench led us into analyzing the concepts of wireless charging as well as confirming the working of the discussed circuit along with calculations

## 2. CONCLUSION

This paper validates the charging circuit discussed in figure 2, whereas the use of PP topology proved to be a feasible option for utilizing it in wireless charging. The paper discussed a complete set of calculations needed to satisfy the wireless transmission, whereas the various effects on the wireless system depending upon the change in different parameters is also discussed.
As to completely assess the proposed equations and discussed circuit a maximum of 5W power was delivered by a 6 V input through the designed charger with an air gap of 1–10 mm. It has been observed that this system has low-voltage stress to the resonant capacitors and low current stress on the MOSFETs. The system was able to transfer with an efficiency of 83.3%.

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Compared with the conventional conductive chargers, WPT offers extreme safety and more convenience. However, coil gap certainly have a great negative impact on the energy transfer. Although within the effective range, the WPT system can also achieve an overall efficiency of around 80%, the charging design is still not able to compete with 90% efficient conductive chargers.

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