Hybrid wireless power transfer in smartphone

Midhun P M
B.Tech Student, Electrical and Electronics Engineering Dept., A P J Abdul Kalam Technological University, Kerala, India

***Abstract*- Wireless power transfer (WPT) technology utilizes energy-contained fields to deliver electric power from the transmitter to the receiver side, removing the direct metal-to-metal contact .WPTSs, in general, can be classified into inductive power transfer systems (IPTSs), coupled magnetic resonance systems (CMRSs) , and capacitive power transfer systems (CPTSs). This paper proposes a combined inductive and capacitive wireless power transfer (WPT) system. The simplicity and low cost of capacitive interfaces makes them very attractive for wireless charging stations. The working principle of the IPT+CPT system is analyzed to derive the expression of the output power and the system design process. Capacitive power transfer (CPT)utilizes high-frequency electric fields to transfer electric power, which has three distinguishing advantages: negligible eddy-current loss, relatively low cost and weight, and excellent misalignment performance. IPT is most common and is applicable to many power levels and gap distances. lnductive power transfer (IPT), which is based on magnetic field coupling. This paper introduces a DC–DC buck converteron the secondary side of the capacitive power transfer system.**

Index Terms- wireless power transfer, Inductive power transfer, capacitive power transfer, dc-dc converter.

1. INTRODUCTION

The Energy Information Administration's records show that half of the electrical plants are high polluting coal plants. As a result of the greenhouse effect certain parts of the earth is going to inhabitable by 2050.One of the solution is to reduce greenhouse gas emissions and support alternative power generation, and transmission.

One sustainable technology can be used is wireless power transfer (WPT). WPT is an emerging technology with an increasing number of potential applications to transfer power from a transmitter to a receiver(mobile).Wireless power transfer technology can be divided into two categories: inductive power transfer (IPT) and capacitive power transfer (CPT). The IPT system utilizes magnetic fields to transfer power, and the CPT system makes use of electric fields. In this paper, IPT and CPT are combined to obtain maximum power transfer. IPT is most commonly used and is applicable to many power levels and gap distances. CPT is only applicable for power transfer applications with inherently small gap distance due to the constraints on developed voltage. The coupling coefficient is a parameter which decides performance of the system.

The coupling coefficient of WPT is given by

$$k = \frac{M}{\sqrt{L_1 L_2}}$$

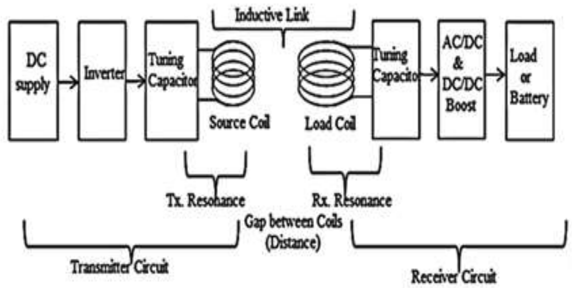
Where L1 and L2 are the self inductances of the coils and M is the mutual inductance between them.

When the value of k is high, the power transfer will be easier with higher efficiency, lower voltage and having good lateral tolerance. In this paper, both the IPT and CPT are combined to get maximum power transfer and efficiency also increases because the effects of both added and the resulting power is transferred to the receivers. The combination of IPT and CPT is known as hybrid wireless power transfer (HWPT).The HWPT for smartphone is evaluated in this paper.

1.1 Wireless power transfer system:

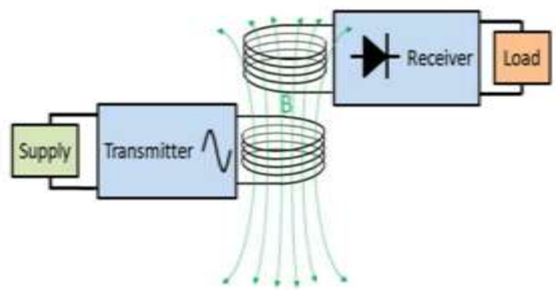
It is defined as the transmission of electrical energy from a power source to an electrical load without connecting wires. WPT system is reliable, efficient, fast, low maintenance cost, and it can be used for short range or long range. Working principle of wireless power transfer is that the two objects having similar resonant frequency and magnetic resonance tends to exchange the energy, while dissipating relatively small energy to the off-resonant objects. Figure showing WPT

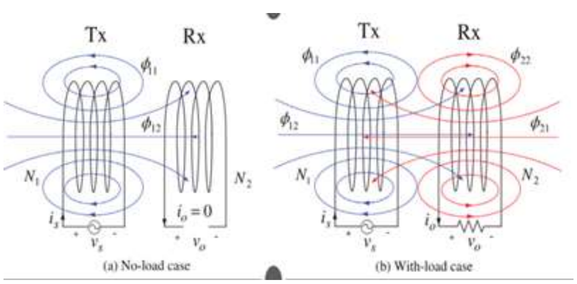
Fig1.wireless power transfer system.



This WPT charging gives a far lower risk of electrical shock because it is galvanically isolated. In WPT the coupling coefficients reducs when the transfer distance increases.

1.2 Inductive power transfer:





As the source current flows, magnetic flux is generated from the Tx coil, where part of the magnetic flux circulates (ϕ11) and the rest of it intersects the Rx coil (ϕ12), which incurs an induced voltage. Because there is no load current, there is no magnetic flux generated from the Rx due to its current; however, there is an induced open voltage. The Rx coil also generates magnetic flux ina similar way to the Tx. This induced voltage at the Tx coil may affect the source current, which again results in a change of the Tx magnetic flux (ϕ11 and ϕ12).The basic block diagram of IPT

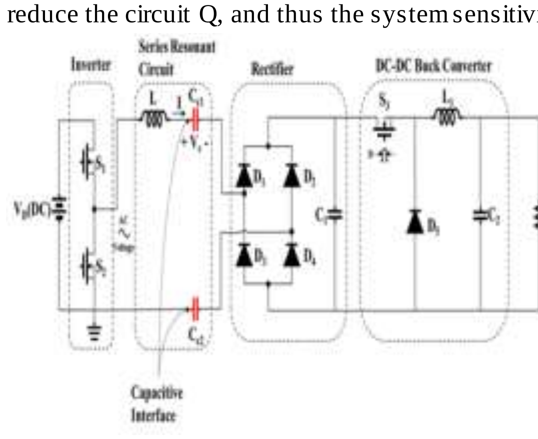
The magnetic field with strong intensity generated by the source coil has been received by the resonantly coupled load coil in the receiver. Then the voltage is harvested in the receiver over a wider air-gap with minimum loss. In order to ensure the compensation technique to reduce the stray and inter-turn capacitances, both coils must be tuned at the resonant frequency. The dc bias voltage is converted into AC pulses through an inverter, which would energize the inductively coupled source coil. Then, it transmits energy magnetically to the remotely located target load, to be powered or battery to be charged. Depending on the distance, Tx and Rx coils constitute a weak magnetic coupling and it can be improved by using a core. The value of K in IPT is improved by increasing the coil area and optimising the coil structure.

1.3 Capacitive power transfer:

This power transfer system based on electric field coupling (capacitive coupling) with less voltage across the coupling interface and circuit quality factor by using a DC–DC converter, which resulted in a safer and less sensitive system while maintaining sufficient delivered power and high efficiency. The high voltage stress across the coupling interface increases the probability of dielectric breakdown and sparks occurrence.

System safety becomes an issue as the related leakage electric field emissions around the plates increase beyond the safety margins. 4. This result in lower efficiency, decreased ability to deliver power, and increased difficulty in offering commercially accepted systems.

It uses DC–DC buck converter on the secondary side of the capacitive power transfer system to reduce the voltage and electric field across the interface, and to reduce the circuit Q, and thus the system sensitivity.



Compared to IPT, CPT has advantages such as reduced cost and weight .CPT has the ability to transfer energy through metal. Therefore it can be used for wireless charging of smartphone.

2. HYBRID WIRELESS POWER TRANSFER

HWPT is an improved method which combines both inductive power transfer and capacitive power transfer.

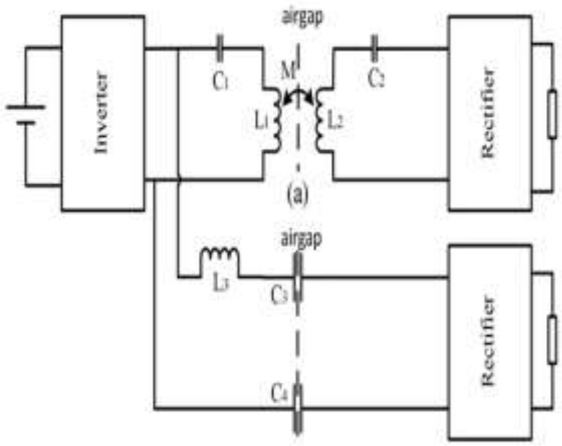


Figure shows the schematic of HWPT

The primary side of the IPT is formed by C1 and L1.The secondary side is formed by C2 and L2.The CPT is Formed by L3, C3 and C4.

The CPT branch consists of two capacitors and it is formed by 4 plates. Two of these plates are connected to the primary side of IPT branch and other two plates are connected to the smartphone. The primary side of IPT and CPT is connected to high frequency inverter. The secondary side of the IPT is followed by the rectifier and to the load .The secondary side of CPT is connected to rectifier and then to the DC-DC buck converter to reduce the voltage and electric field across the interface.

3. MODELING AND DERIVATION

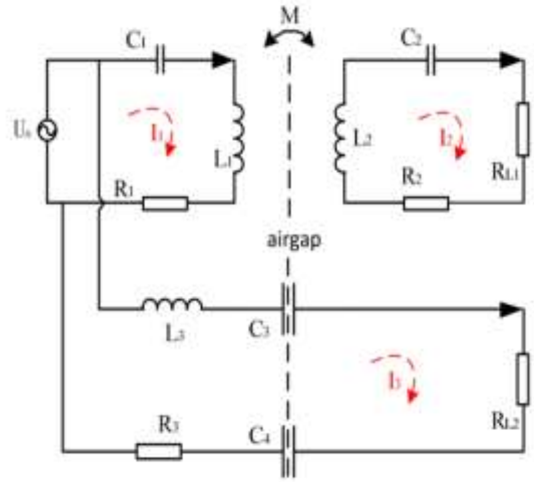
The primary side of the inverter simplified in to the AC voltage source. The proposed HWPT circuit consists of three resonant tanks. All the resonant tanks are tuned to the same resonant frequency. The frequency of the Ac source is given as

The equivalent of HWPT is given below.

3.1 Modeling of IPT branch:

By KVL, the voltage of primary and secondary side of IPT branch is given by

$$F_{U_s} = \frac{1}{2\pi\sqrt{L_1C_1}} = \frac{1}{2\pi\sqrt{L_2C_2}} = \frac{1}{2\pi\sqrt{L_3\frac{C_3C_4}{C_3+C_4}}}$$



The mutual inductance M is given by

$$\begin{cases} U_s = \left(R_1 + j\omega L_1 + \frac{1}{j\omega C}\right)I_1 + j\omega M I_2 \\ 0 = j\omega M I_1 + \left(R_2 + j\omega L_2 + \frac{1}{j\omega C_2} + R_{L1}\right)I_2 \end{cases}$$

coil and secondary side coil can be simplified as the reflected impedance and it is given by

$$M = k\sqrt{L_1 L_2}$$

3.2 Modeling of CPT branch:

The reflected impedance of CPT branch is given by

$$Z_{ref1} = \frac{(\omega M)^2}{R_2 + j\omega L_2 + \frac{1}{j\omega C_2} + R_{L1}}$$

4. DESIGN GUIDELINE AND CONSIDERATION

The HWPT system for wireless charging of smartphone is considered.

$$Z_{ref2} = j\omega L_3 + R_{L2} + R_3 + \frac{1}{j\omega C_3} + \frac{1}{j\omega C_4}$$

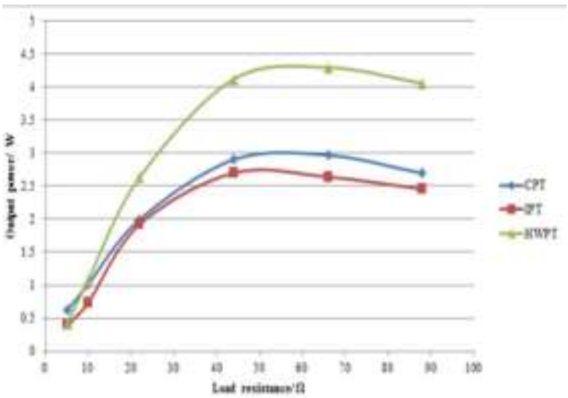
The space inside the smart phone is limited. The shielding aluminium plate can be used as the receiver side plate. The capacitance between the shielding plate and the primary side is given by

$$C = \varepsilon \cdot \varepsilon_0 \frac{S}{d}$$

S is the area of the shielding plate.
For smartphone S is around 30-80cm^2.
d is the distance between two plates.

Next design consideration is the inductive heating problem of IPT. When the magnetic field is having high frequency, it will generate eddy current in the metallic components and ICs of the smartphone. This decreases the power transfer efficiency and also threat to the functioning of the smartphone. This can be solved by making CPT large to shield maximum field.

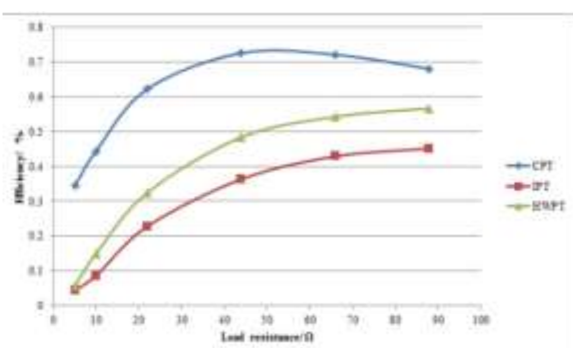
4.1 Comparison of output power of HWPT, IPT and CPT.



Green represents the output power of HWPT.
Blue is the output power of CPT and Red is for IPT. The output power of HWPT is higher than IPT and CPT.

4.2 Comparison of efficiency of HWPT, IPT and CPT.
The power transfer efficiency of CPT is higher than IPT and HWPT. When load resistance increases, the efficiency of HWPT and IPT also increases.

5. CONCLUSION



An improved wireless power transfer is implemented known as the Hybrid wireless power transfer system. The Hybrid wireless system is the combination of inductive power transfer system and capacitive power transfer system. The proposed system consisting a single inverter. By developing HWPT system the coupling coefficient is increased. There by high output power can be obtained. It uses DC–DC buck converter on the secondary side of the capacitive power transfer system to reduce the voltage and electric field .And thereby reduces the Q and the sensitivity of the system.

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