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# A Dual Wireless power transfer-Based Battery Charging System for Electric Vehicles

**S. Ravi Teja, Sk.Moulali, M. Nikhil, B. Ventaka Srinivas**

***Abstract:** Wireless battery charging of electric vehicles is been under development to commercial scale in recent past. Inductive Power transfer has established usage in wire-less power transfer. This paper proposes an improved dual power transfer system for wireless battery charging for electric vehicle charging application. The working principle being obtaining resonance between filter inductance and capacitive transfer element and thus improving power transfer capability and efficiency of the charging system. A 3kW dual power transfer battery charging system is designed and implemented. The equivalent model of circuit is simulated in MATLAB/SIMULINK. The dual power transfer system reported a high efficiency with high switching frequency and performs better under misalignment than the inductive power transfer System.*

***Index Terms:** Dual power transfer, Electric vehicle (EV), electric field, magnetic field, Misalignment, resonant circuit, Coupling coefficients, Mutual Inductance.*

## I. INTRODUCTION

Electro-Magnetic power transfer is the transfer of Electrical energy without wires and in-between air-gap from primary side to secondary side [1]. Two effective methods to achieve WPT, the inductive power transfer (IPT) and capacitive power transfer (CPT) [1]. The IPT system uses magnate fields to transfer power, which has made many achievements. The transfer power can be up to megawatt level [3], and the transfer efficiency can reach up to 96%. The development of the IPT system has paved the way towards various applications, such as electric vehicle charging, bio-medical applications, track-moving system, mobile communication devices etc [2][3]. Major drawbacks of power transfer systems are the wiring associated trip hazards and the contact wear-out. In an effort to overcome these drawbacks, an IPT system such as the one depicted and demonstrates many advantages including convenience of being cord less making it unnecessary to plug and unplug the bulky cable, insusceptible to weather impact since the primary side can be embedded under-ground for EV charging applications, significant reduction to an implant systems, and inherently safe during charging since there is no exposed conductors. Despite those advantages, there are still some issues to be addressed for IPT systems [4].

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Gap and horizontal misalignments between transmitter and receiver would be a critical problem because the power transfer efficiency greatly depends on the relative positions of the primary and the secondary coils in the IPT system. Therefore, the power transfer efficiency is drastically reduced when a gap variation or misalignment occurs between the inductive coils [5]. In the battery charging application, the resonant circuit is, therefore, not affected by the battery voltage variation. Therefore, it is suitable to provide constant current charging condition to the batteries. Another benefit of LCC topology is that it can provide nearly unity power factor to the input side inverter, so there is almost no reactive power injected into the resonant tank, which results in high efficiency for this topology [6], [7]. The advantage of dual power transfer through inductive plus capacitive elements for power transfer is appreciated in [8] and [10]. Simulink model of open loop and closed loop wireless power transfer circuits are shown in [11]. This paper resorts sizing of components for dual wireless power transfer and thus estimating the resonant switching frequency and charging time calculation for misalignment of transfer and receiving systems. This paper is organized as follows. Section I presents the introduction providing various challenges in wireless power transfer. Section II presents proposed topology and its working. Section III presents the simulation results and Section IV presents conclusions.

## II. CIRCUIT TOPOLOGY AND WORKING PRINCIPLE

The circuit topology of dual power transfer based wireless battery charging system is shown in fig.1. The transfer system is modelled as primary coil of coupled inductor and coupling capacitor plates P1 and p3 fed by high frequency h-bridge inverter with LC filter formed by $L_{f1}$ and $C_{f1}$. Receiving system on vehicle forms the secondary coil of coupled inductor and coupling capacitor plates P2 and P4 with filter $L_{f2}$ and $C_{f2}$ rectified by diode bridge rectifier which is fed to battery on the vehicle. Here an equivalent resistive load $R_L$ is shown. The capacitive transfer is modelled as composite network formed by four plates P1 – P4 [10] as shown in fig.1.

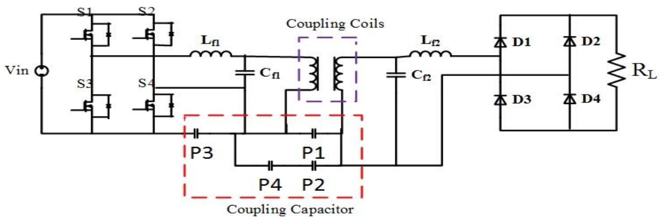


**Fig. 1** *Circuit topology for combined inductive and capacitive power transfer based wireless charging system*


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The circuit is analysed treating output of inverter on transmission side and input to diode bridge rectifier on receiving side as two ac voltages sources. The operation of the circuit topology can be is described as a superposition of responses due to two voltage sources mentioned above. On to the primary side i.e; on the system at charging station two parallel resonances are formed one with secondary side filter and second on to primary side filter inductance and power transferring capacitor. A similar response can be explained at secondary side i.e; on to on-vehicle charging board. Thus, it acts as a constant current source as seen from either side.

## III. SIMULATION RESULTS

A 3kW output power charging system is designed for a lead-acid battery with specifications shown in Table1. The sizing of coupled inductor, capacitive transfer plates, LC filters on primary and secondary side is based on calculations as explained in [10] and are provided in Table 2.

| | |
|---|---|
| Nominal voltage | 320V |
| Rated capacity | 6 kWH |
| Ampere hour | 20AH |
| Module Specifications | 48V, 10A (7 Modules) |
| Power | Around 3kW |
| Nominal full-charge time | 2 hours |

**Table 1 Battery specifications**

| Parameter | Design value | Parameter | Design value |
|---|---|---|---|
| $V_{in}$ | 310V | $V_{out}$ | 320V |
| K | 0.9 | $K_c$ | 0.052 |
| $f_{sw}$ | 1 MHz | $C_s$ | 5.0 pF |
| $L_{f1}$ | 14.2μH | $L_{f2}$ | 14.2 μH |
| $C_{f1}$ | 1.78nF | $C_{f2}$ | 1.78nF |
| $L_1$ | 256.2 μH | $L_2$ | 264.1 μH |
| $C_1$ | 96.1 pF | $C_2$ | 96.1 pF |

**Table 2 Component sizing for charging system**

The simulation is performed in MATLAB/SIMULINK considering parameters provided in Table 2. The simulation is done for various percentages of misalignment and output power in each case with only inductive power transfer and with dual power transfer. The following results were obtained. Figures 2 and 3 presents the voltage at input filter and output power for only inductive power transfer for 16 percent misalignment which corresponds to inductive coupling coefficient of 0.9.

Figures 4 and 5 presents the voltage at input filter and output power for inductive plus capacitive power transfer for 16 percent misalignment which corresponds to inductive coupling coefficient of 0.9 and capacitive coupling coefficient of 0.86 [10].

Figures 6 and 7 show the output power with 25 percent misalignment for only inductive and dual power transfer respectively. The maximum output power is obtained with no misalignment and is decreases with increment of misalignment.

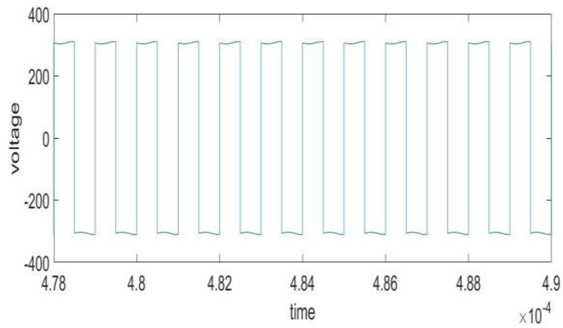


**Fig.2 Voltage waveform at input of primary side filter for IPT system for 16 percent misalignment (K =0.9)**

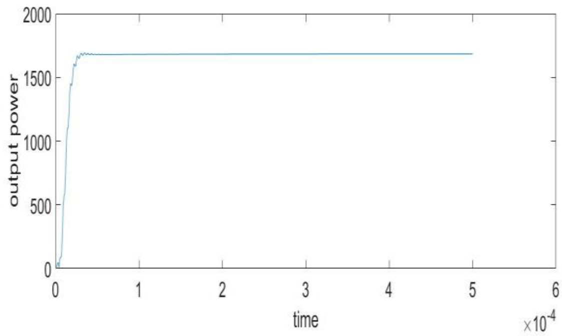


**Fig.3 Output power for IPT system for 16 percent misalignment (K =0.9)**

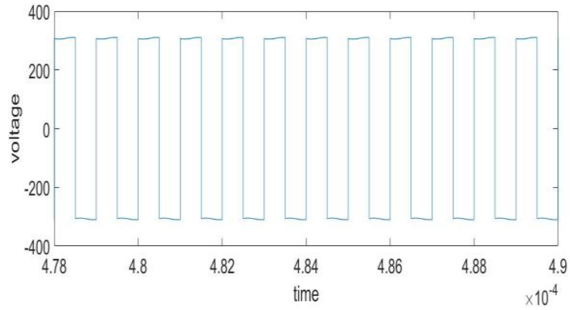


**Fig.4 Voltage waveform for at input of primary side filter with IPT plus CPT for 16 percent misalignment (K =0.9 and ε=0.86)**

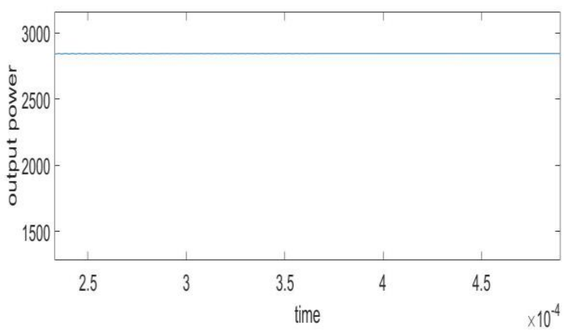


**Fig.5 Output power with IPT plus CPT for 16 percent misalignment (K =0.9 and ε=0.86)**


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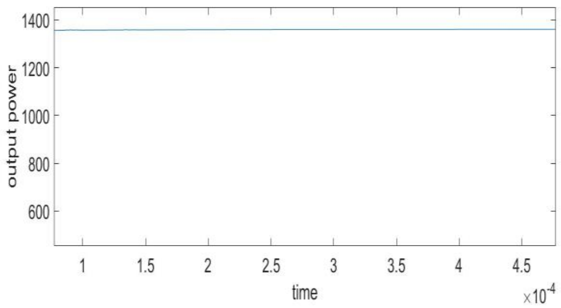


**Fig.6 Output power for IPT system for 25 percent misalignment (K =0.8)**

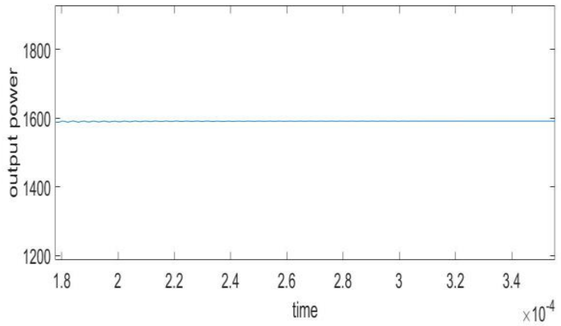


**Fig.7 Output power with IPT plus CPT for 25 percent misalignment (K =0.8 and ε=0.78)**

The output power with increasing misalignment for only inductive transfer and dual power transfer is calculated and is presents in Table 3.

It presents the effectiveness of dual power transfer with more output power is made available even with higher degree of misalignment.

**Table 3 charging o/p power for various degree of misalignment**

| Percentage misalignment | K | ε | output power for only IPT | output power for IPT and CPT |
|---|---|---|---|---|
| 16 | 0.9 | 0.86 | 1700 | 2842 |
| 25 | 0.8 | 0.78 | 1360 | 1620 |
| 33 | 0.7 | 0.67 | 1020 | 1356 |
| 40 | 0.6 | 0.59 | 760 | 980 |

The charging time for various degree of misalignment for dual power transfer-based charging system is estimated as per corresponding output power.

Figure 8 shows the increase of charging time with decrement in available charging system output power owing to misalignment.

Figure 9 represents the similar result in terms of percentage misalignment.

The output power and corresponding charging time for various degrees of misalignment is shown in Table 4.

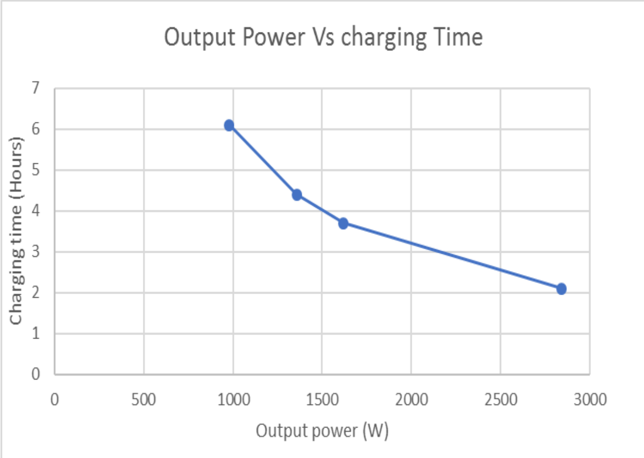


**Fig. 8 Charging system output power Vs Charging time for full charge of battery**

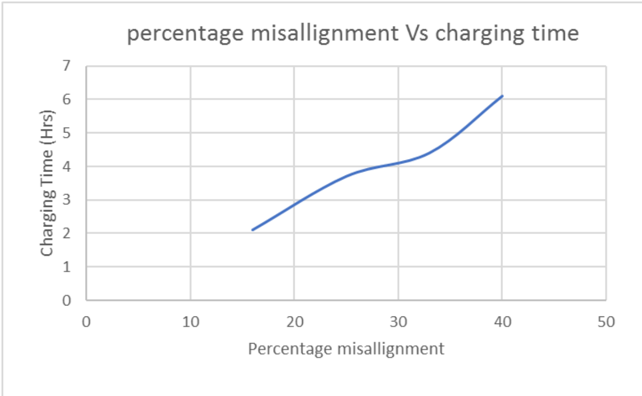


**Fig. 9 percentage misalignment Vs Charging time for full charge of battery**

**Table 4 Battery charging time for various degrees of misalignment**

| Percentage Misalignment | Output power (W) | Full Charge time (Hrs) |
|---|---|---|
| 16 | 2842 | 2.1 |
| 25 | 1620 | 3.7 |
| 33 | 1356 | 4.4 |
| 40 | 980 | 6.1 |

## IV. CONCLUSION

The sizing of components for dual power transfer is carried out for a 3-kW power output wireless charging system for electric vehicles with 20Ah battery unit. The charging system is simulated in MATLAB/IMULINK for various degrees of misalignment. A comparative analysis on output power availability of charging system for varying degrees of misalignment is made and proved the effectiveness of combined power transfer in terms of higher output power availability with misalignment. Also, the charging time estimated with varying degrees of misalignment. Thus, a dual wireless power transfer system is proven to be a better solution for electric vehicle charging systems.


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