Three or Four Plate Capacitive Wireless Power Transfer System for Electric Vehicle Charging

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ABSTRACT

Although inductive power transfer (IPT) systems dominate the wireless power transfer (WPT) technologies, recently capacitive power transfer (CPT) systems also have received significant attention due to their outstanding benefits such as negligible eddy- current loss, higher reliability, better misalignment performance, lower cost, lightweight, and lower EMI . The CPT technology has many application areas in wireless charging concept. The first example that comes to mind for large transfer distance applications is the wireless electric vehicle (EV) charging . In addition, the effects of dielectric materials on capacitive coupler structures have great importance for increasing the power transfer capability and electric field strength . here three or four metal plate is proposed for EV charging applications . Herein, the chassis of a vehicle and earth ground are high- lighted to substitute for three or four plates used in conventional six plate structures. In addition, a three or four plate capacitive coupler structure provides a decreased number of plates and cost reduction in CPT applications. Then, three or four plate coupler structure to provide less electric field emission for large transfer distance applications. Nevertheless, the number of coupling capacitances to realize the equivalent circuit and increased cost with six metal plates are the drawbacks. the last conventional capacitive coupler structure called as an electric field repeater to enhance the transfer distance in CPT systems. However, the low system efficiency is the disadvantage of the coupler.

INTRODUCTION

The wireless power transfer (WPT) technology has acquired much attention recently due to its conveniences, safety, and the need of mobility during a battery charging. The WPT for the batteries charging includes two non-radiative technologies: capacitive power transfer (CPT), and inductive power transfer (IPT).

Much studies in recent years have focused on the CPT technology, due to its benign features, which offers power transfer through a metal barrier, system simplicity, low eddy current loss, and less electromagnetic interference (EMI). This technology could be used in low/high-power levels, and small/large air-gap applications .

The idea of the CPT technology comes from the principle operation of a capacitor. The conductive plates of a capacitor separated by an air-gap (d), which is usually filled with a dielectric material for purpose of insulation.

The operation principle of the CPT technology is similar to a capacitor excited with an AC power.In an AC excitation, the direction of the electric field is reversed each half-cycle, then, the charge and discharge are alternately repeated.Based on this approach, the capacitor is considered as passing an AC current .

In a CPT system, the capacitive coupler could be represented by two plates, four plates or more,.The CPT technology has many possible uses in the battery charging fields, such as charge smartphones, E- book readers, laptop, digital camera, and biomedical devices.

One way to enhance a CPT system performance is adding compensation circuit to get an electric field in resonance (EFR), in order to get high voltage on the transmitter plate(s) that becomes capable to produce enough electric fields for the capacitive charging .

The whole performance of a CPT system could be improved by using a compensation circuit topology and more recently, that the transmission distance could be doubled by using a repeater . The repeater is plate(s) which usually has the same configuration as the transmission and receiver plates, but the power supply port is shorted. The repeater plates placed between the transmitter and receiver plates

1.2 SYSTEM WORKING PRINCIPLE

The structure of a two-plate CPT system for electric vehicle charging applications.On the primary side, an inverter is used to provide an ac excitation,followed by a compensation circuit. The earthground P1 and a metal plate P2 work as the transmitter, and there is an insulation layer between them.

The parasitic capacitance between the vehicle chassis and the earth ground is used as the current returning path. In practical applications, the earth ground can also be connected with a metal plate to further reduce the conductive loss. It needs to be emphasized that this ground-side plate is optional. If it is used, it should have a good connection with the earth ground.example, it can be buried into the ground to maintain a good connection. Then, as long as the connection with the ground is good enough,the size of the ground-side plate can be much smaller than the vehicle chassis. Since the ground-side plate directly connects with the compensation circuit, all the parasitic displacement currents from the chassis to the earth ground will be aggregated to this ground-side plates and then flow back into the compensation circuit.

1.3 Capacitive power transfer concept

The typical CPT system consists of transmitter and receiver sides .

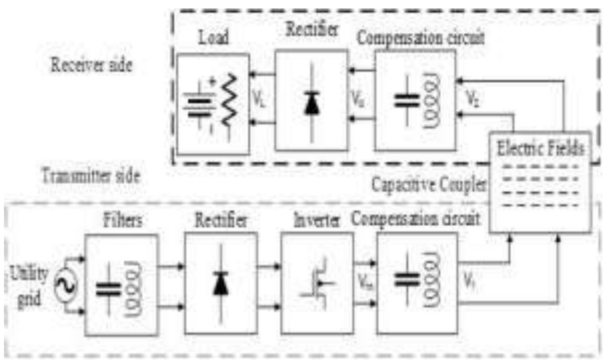

FIG 1.1 CPT SYSTEM

The transmitter side consists of filters which prevent the unwanted harmonic from injected back into the utility grid, a half/full-bridge rectifier for AC/DC power conversion, an inverter that converts the DC power into AC power at high-frequency before exciting the transmitter plate through a power cable .

When the plate of the transmitter side is positively charged (passive plate), the second plate of the same side has an opposite charge i.e. negative (active plate) and so on. This produces a phase altering potentials, which produces an alternating electric field between the capacitively coupled plates, then the power is delivered from the transmitter plate(s) to the receiver plate(s) .

At the receiver side, a half/full bridge rectifier is required to convert back the AC electric power from the receiver plate into an DC electric power to supply it into a load .A DC/DC converter could be used before the inverter for purpose of voltage regulation.

The power cable material, diameter, length, and weight have to be chosen thoroughly during designing the power stage. The coaxial cable proves its worthiness to handling high power ratings at high frequencies with minimum eddy current, and skin effect losses . Also, there are several kinds of the inverters can be used.

1.4 Capacitive coupler structure

The capacitive coupler consists of the transmitter and receiver conductive plates, they formed a capacitor in the air. The coupling plates are coated with a suitable dielectric for purpose of insulation and improving coupling capacitance (Cm). The plates are made of conductive materials, such as silver, copper, zinc, aluminium etc. It was noted by Ramani K. et al., that the aluminium provides a power density higher than the zinc .

In an experiment that conducted by Ramani K. et al., it was observed that the efficiency of power transmission is affected by the thickness of coupling plates and dielectric material that has been used i.e. glass . The dielectric constant, electric field breakdown and loss tangent are parameters usually used to describe characteristics of a dielectric material . The atmospheric conditions should, also,Capacitive coupler structure

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Nikola Tesla is the first one who used the CPT technology, that was in 1891 .However, the first CPT system was made just in 1966. It consists of two pairs of plates and the water was used as a dielectric material.

The first CPT system was used to transmit and receive signal at the frequency of 100 kHz .

1.5 Capacitive coupler configurations

Bipolar coupler

Bipolar coupler is the most popular configuration. It includes two pairs (four plates) of electric field coupling plates with a current returning path from a load to the power source. .

However, between any capacitively coupled plates, there are many parasitic capacitances appearing in a practical application, such as lateral capacitance, which appears between any two edges of conductors with the same plane, and fringing capacitance which arises between the edge of a plate and the surface of another plate .The plates of the bipolar coupler are usually arranged in two rows as shown in Figure .

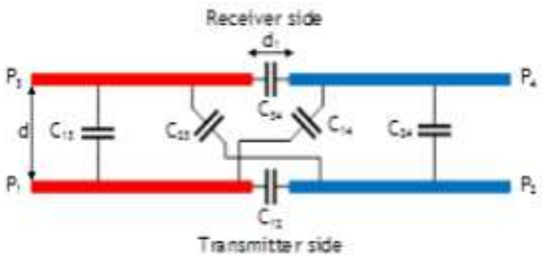

Figure1.2 :Bipolar capacitive coupler with row arranged plates

Also, the plates of the bipolar coupler are usually arranged in a column as shown in Figure . be taken into consideration during the design of a CPT system, especially for dynamic charging and large air-gap applications, because the loss tangent and permittivity of a dielectric material become an area of concern .

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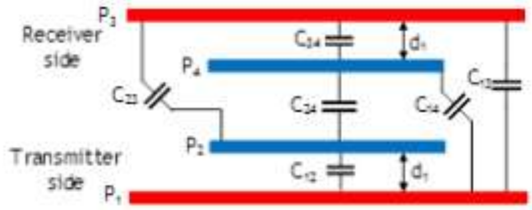


Figure1. 3. Bipolar capacitive coupler with column arranged plates

As can be seen from Figure 2, the plates P2 in the transmitter side and the plate P4 in the receiver side are for the current-sending path from a power source into a load.

The plate P1 in the transmitter side and the plate P3 in the receiver side are for current returning-path from the load into the power supply through the capacitance.

1.6 Equivalent Capacitance

The coupling capacitance (Cm) and coupling coefficient (k) are parameters usually used to describe the capacitive coupler. The Cm is the equivalent capacitance that appear between the capacitively coupled plates. The k is the fraction of the electric field that links the transmitter and receiver plates. The k is geometrical parameter; therefore, this parameter is position dependent. The relation between Cm and k is given by equation .

$$\mathbf{Cm = k . \sqrt{C1 . C2}}$$

where C1 and C2 are equivalent self-capacitors of the parasitic capacitances in the transmitter and receiver sides, respectively.

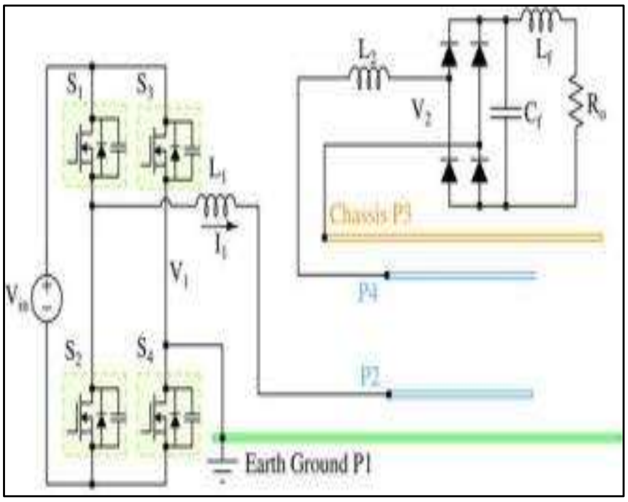


FIG 1.4COUPLING CAPACITOR DESIGN

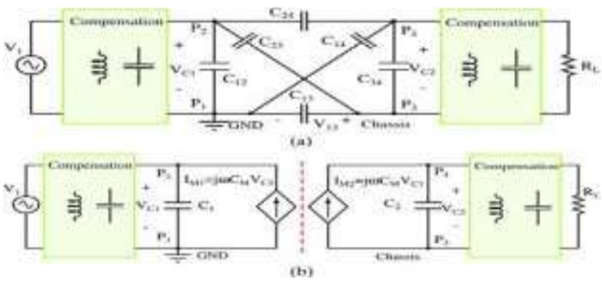


FIG 1.5Equivalent model of a two-plate CPT system with ground and chassis. (a) Six-capacitance model. (b) Behavior-source moel.

Kilowatt CPT systems require nanofarad scale coupling capacitance given the frequency and efficiency capabilities of power electronics . To increase the coupling capacitance for a given area, it is desirable to increase the effective permittivity of the volume between the capacitor's metal plates by inserting a dielectric. This dielectric material is typically coated directly on the primary (transmitter) and/or secondary (receiver) surfaces and ensures galvanic isolation between them. Ceramic coatings such as titania have been proposed for their higher relative permittivities (~80) and dielectric strength (~70MV/m) . However, for most applications where the secondary is a mobile object (e.g. an EV) and comes into contact

$$C1 = C12 + \frac{(C13 + C14) \cdot (C23 + C24)}{(C13 + C14 + C23 + C24)}$$

$$C2 = C34 + \frac{(C13 + C14) \cdot (C23 + C24)}{(C13 + C14 + C23 + C24)}$$

$$CM = (C13C24 - C14C23)/(C13 + C14 + C23 + C24)$$

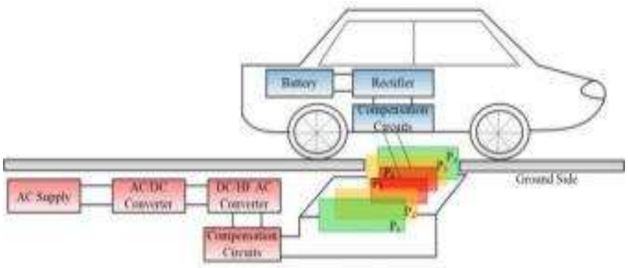
with a stationary primary surface for periodic charging, there will always be an air gap. Unless great care is taken in machining, no rigid surface is truly flat, let alone two rigid surfaces pressed together, ultimately introducing an air gap. This minute air gap may negate the benefits of the higher relative permittivity of the dielectric coating on the coupling surfaces . there are two layers of dielectric in the capacitor (i.e. coating and air gap). The capacitance can be calculated by (1), in which d_a and d_c are the thickness of the air gap and coating respectively, and ε_r is the relative permittivity of the coating. The overall equivalent permittivity is calculated

If the air gap thickness is similar or larger than the coating, the air gap will dominate the capacitance. This is the analogous to an air gap in magnetic circuits dominating the reluctance no matter how permeable the iron may be. Therefore, decreasing the size of the air gap and inserting a dielectric is the only way to increase the capacitance.

3.1EXISISTING SYSTEM:

A novel six-plate vertical coupler arrangement for a static CPT system to reduce the plate size and adjust the transfer distance. The primary source of the CPT system is connected to the four aluminum plates in the TX. Mica is used as a dielectric material between the RX plates, which come from the vehicle. The performance of the LCL compensation circuit is evaluated as part of this research , and it is then implemented on both the TX and RX sides to increase the voltage and transfer power. The primary side resonant inverter produces a high-frequency ac source, while the secondary side rectifier converts ac to dc and is connected to the battery for charging.

The dimensions of the plates are utilized to calculate the coupling capacitances between the plates. To determine the dimension, this work considered the plate ratio (*pr*), which is defined as the ratio of short plate length to long plate length. Initially, the plates are optimized to have an equal air gap distance, and the plate ratio is determined using Maxwell. Applying the finite element analysis , the mutual and self-capacitances of the proposed static CPT system are calculated. Based on the above mutual and self- capacitances, the compensation circuit parameters are designed. After calculation, the LT spice simulation is used to examine the proposed CPT system's overall circuit. Based on the LT spice result, the experimental setup is designed with a 6.06 kW output power . In addition, the voltage stress and electric field emission in the surrounding medium is calculated, and it reaches acceptable safety limits.



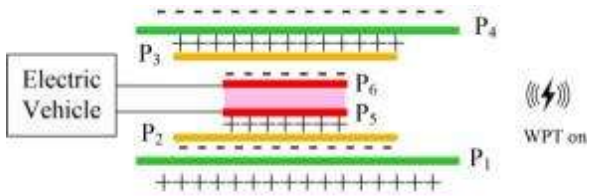


FIG3.1 SIX PLATE MODEL

3.2 DISADVANTAGE OF EXISISTING METHOD:

- The arrangement can be modified to accommodate a vehicle side plate in a existing parking system by adjusting the gap between the plates and optimizing the dielectric material.
- To simplify the dimension calculations, all plates are arranged with the same airgap distance, and their shape is assumed to be square.
- The plate's shape does not affect the coupling. In practice, coupling plates maybe of any shape, but it is necessary to maintain the plate area.
- To distribute the electric fields and produce a strong coupling, the plate's edges are reduced from outer plates to inner plates.

WORKING MODEL

The structure of a three or four-plate CPT system for electric vehicle charging On the primary side, an inverter is used to provide an ac excitation,followed by a compensation circuit. The earth ground $P_1$and a metal plate P_2,$P3$,P_4work as the transmitter, and there is an insulation layer between them.

The parasitic capacitance between the vehicle chassis and the earth ground is used as the current returning path. In practical applications, the earth

International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 09 Issue: 07 | July - 2025 SJIF Rating: 8.586 ISSN: 2582-3930

ground can also be connected with a metal plate to further reduce the conductive loss. It needs to be emphasized that this ground-side plate is optional. If it is used, it should have a good connection with the earth ground. For example, it can be buried into the ground to maintain a good connection. Then, as long as the connection with the ground is good enough,the size of the ground-side plate can be much smaller than the vehicle chassis. Since the ground-side plate directly connects with the compensation circuit, all the parasitic displacement currents from the chassis to the earth ground will be aggregated to this groud-side plates and then flow back into the compensation circuit.

A full-bridge inverter is used on the primary side to provide an ac excitation. A full-bridge rectifier and a low- pass filter are used on the secondary to provide a dc current to the output resistor R_O . Two compensation inductors L_1 and L_2 are adopted on the primary and secondary sides, respectively, to resonate with the capacitive coupler. Using the fundamental harmonics approximation method and the coupler model , it can be simplified .

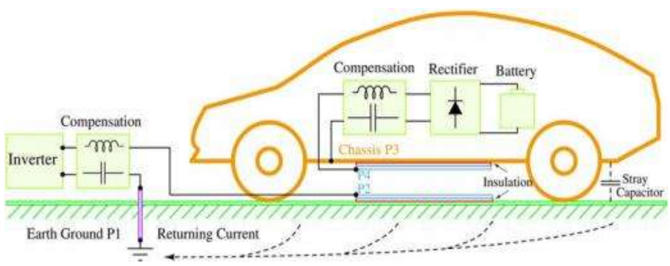


FIG 3.2Structure of a four-plate compact CPT system for electric vehicle charging applications.

EXPERIMENTAL ANALYSIS

CAPACITOR VALUES SELF CAPACITANCES:

C12 (Capcitance between Ground to Transmitter Plate) C12=4700pf (fixed)

C34(Capacitances between Vehicle Chassis to Receiver Plate) C34=100pf (fixed)

COUPLING CAPACITACES:

C24 (Capacitances Between Transmitter and Receiver Plate)

As per Distances deceased varied Capacitances

Value increase distances of P2-P4

D = 7cm

C24= 33PF

D = 2.35cm

C24= 100PF D = 1.30cm

C24 = 180PF D = 0.5cm

C24 = 470PF D = 0.05cm

C24 = 4700PF

PARASITIC CAPACITOR :

C13 (Capcitance between Ground to Vehicle Chassis) C13 = 47pf (fixed)

We use 9V and 50 hz Supply so Stray Capacitances between (C14) and (C23) Not forms sufficiently, Hences Diagonal capacitances C14and C23 Negligible

IDEAL or LOSS LESS Capacitive Power Transfer

Without Parasitic capacitance (output voltage)

C13=0

(P2-P4) Distances	C12	C34	C13	C24	Input voltage	Output voltage
7cm	4700pf	100pf	0	33pf	9v	0.6v
2.35cm	4700pf	100pf	0	100pf	9v	2v
1.308cm	4700pf	100pf	0	180pf	9v	2.7v
0.5cm	4700pf	100pf	0	470pf	9v	6v
0.05cm	4700pf	100pf	0	4700pf	9v	9v

Capacitive Power Transfer (loss include) With

Parasitic capacitance (output voltage) C13=47pf

(P2-P4) Distances	C12	C34	C13	C24	Input voltage	Output voltage
7cm	4700pf	100pf	47pf	33pf	9v	0.5v
2.35cm	4700pf	100pf	47pf	100pf	9v	1.7v
1.308cm	4700pf	100pf	47pf	180pf	9v	2.5v
0.5cm	4700pf	100pf	47pf	470pf	9v	3.3v
0.05cm	4700pf	100pf	47pf	4700pf	9v	5v

Self Capacitance (P1-P2) (P3-P4)	Coupling capacitance (P2-P4)	Parasitic capacitance (P1-P3) (P2-P3) (P1-P4)

P1 = Ground P2 = Transmitter Plate P3 = Vehicle Chassis P4 = Receiver Plate

CONCLUSION

This letter proposes a two-plate compact CPT system for electric vehicle charging applications. The vehicle chassis and the earth ground are exploited to transfer power, which can simplify the structure of the CPT system. The voltage on the vehicle chassis is studied, which provides three methods to reduce the chassis voltage for safe operation.This paper presents the most important aspects of the CPT systems. The capacitive coupler configurations have been discussed. The Cm and k are geometrical dependent parameters.

Therefore, three or four plates configuration have been proposed to enhance these parameters to minimize the cost of a CPT system in terms of reducing VA rating, and enhance the overall performance.