

# Capacitive Power Transfer With Electric Field Emission Reduced for Electric Vehicle Charging Application

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## 論文内容の要旨

### Thesis Summary

Wireless power transfer (WPT) is a new method to transfer the power between sources and mobile device/s without the use of cables. WPT promising an energy sustainability in many applications offers a simple and effective way to deliver energy. Almost all the previous WPT researches have conducted and used inductive power transfer (IPT) technology. This uses magnetic fields between two or more coils to deliver the energy. In electric vehicle applications, many researchers are trying to design a WPT system to achieve a high-efficiency charging. Since a common known its limitation, such unable to work well where a metal barrier placed between coupling interface and issue related to electromagnetic interference (EMI) appears in the IPT system. Capacitive power transfer (CPT) appears as an alternative to solve this problem. Rather than use magnetic induction between the coupler, CPT apply an electric field resonant (EFR) to deliver the power. With its flexibility in form, lightly in weight, and simplicity in structure, CPT is the future of wireless power.

Since CPT is not yet mature in technology, an improvement of its design challenges need to be addressed. Low power abilities, radiation of electric field (EF) and system scaling are three main issues for CPT. Higher power abilities are only achieved with a large coupling area or a small gap between the coupler. A trade-off is associated with the other two issues, EF strength and system scaling, which conveys to a tinny module and system safety.

Chapter 1 presents an introduction and overview of the capacitive power transfer system, the research scopes and objectives are included. More, this chapter describes a methodology that used in the study. In addition, several work contributions and publications related to the research are provided.

Chapter 2 starts by giving a brief history of WPT innovation, which ranges over a century. How an EV charging technology from the common powered by line to the present wireless power transfer. There is a brief discussion of the merits and demerits of each technology. A CPT basic circuit and fundamental theory is introduced.

Chapter 3 introduces a new approach for reducing EF in CPT system by implementing a single-wire

capacitive coupling interface. The system is analyzed to study the availability of powering the EV wirelessly with considers the radiation of EF surround the interface. The stray voltage appearing to the chassis of EV is also investigated.

Chapter 4 introduces a new term of CPT technology called a shielded-capacitive power transfer, S-CPT. By utilizing an extra conductive plate behind the coupling interface of the conventional CPT system, the new topology has been studied in detail to prove the concept. A simplified design is introduced. An investigation related to the EF emission has been analyzed. A Simulation and experimental research have been verified by the proposed system.

Chapter 5 introduces a scaling factor and design consideration of S-CPT in order to optimize a coupling structure parameter following the design and requirement. An analysis of the inductor series resistance is included in the calculation of total power loss of the S-CPT system. The relationship between the shield coupler gap, the couplers distance, the size of conductive plate, and delivered power has been analyzed and described in this chapter. A recommendation in designing the S-CPT system for scaling consideration is presented.

Chapter 6 introduces a development of Class-E RF inverter with capability of 50 W 6.78 MHz and 300 W 13.56 MHz high frequency power amplifier. GaN MOSFET is used as a switching network provides a high frequency operation of the power amplifier. A power loss of inverter with and without transformer is also analysed. SPICE simulation software is used to define the parameters and to calculate the power loss. Two Class-E RF inverter has been developed, implemented and tested to deliver a power wirelessly to the proposed S-CPT system.

Chapter 7 presents the outcomes of the research work, its contributions and concludes the thesis. It also identifies future research opportunities.

Three main challenges and design guideline for system scaling are introduced for shielding improvement in CPT system. In addition, a new term of “**Shielded-CPT**” is proposed. Firstly, the EF radiation surround the coupling interface is high consider delivers higher power such for EV charging. This thesis proposes a new approach of coupling interface with shielding effect improved by a single coupling structure. An analysis has been performed on the circuit model of capacitive coupling interface. Secondly, other new coupling interface with shield was presented. An improvement regardless of the ground stability on the shielding plate was proposed. Finite element analysis and EF radiation strength analysis, completed with a Spice transient circuit simulation were conducted. Thirdly, simplicity design of Class-E RF GaN MOSFET power amplifier with high power high frequency operation was offered. Design and fabrication of power inverter was implemented to the CPT system. An analysis and extensive experimental results show capability of delivering power with a high efficiency.

The final content of this thesis is design guidelines of shielded-CPT system scaling. A detail mathematical analysis with comprehensive circuit model breakdown was presented. Hardware implementation for validate the design procedure was provided. This guideline covers a wide range of design factor analysis include an inductor power loss, load variations behavior, equivalent series resistance behavior, impedance ratio and power transfer analysis. The result shows significant match between hardware implementation and acquired design factor.