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ELECTRICAL & ELECTRONICS ENGINEERING DEPARTMENT

PROJECT NO: 60
DESIGN OF A WIRELESS POWER TRANSFER SYSTEM WITH CAPACITIVE COUPLING

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ABSTRACT

The capacitive power transfer system is a system that emerges in the area of wireless power transfer. The capacitive system uses high-frequency electric fields to transfer electrical energy.

In this thesis, a wireless power transfer system with capacitive coupling is aimed. The working principle of the capacitive power transfer system has been investigated and analyzed with two equivalent circuit models in the circuit analysis. This model is simplified to an equivalent two-port current source model and π equivalent model. The four plates are arranged vertically for the capacitive coupler structure. The LC compensation topology is used to resonate with the coupler.

Four-plate structure and double-sided LC balanced power transfer system are designed and constructed. The prototype achieved an efficiency of 1.5 cm air gap at a switching frequency of 85 kHz.

INTRODUCTION

Capacitive power transfer system utilizes multiple metal plates to transfer power via electric fields. The electric fields can pass through metal plates without generating significant power losses. Therefore, the capacitive power transfer system is suitable for the electric vehicle charging applications.

General overview of capacitive power transfer system is shown below.

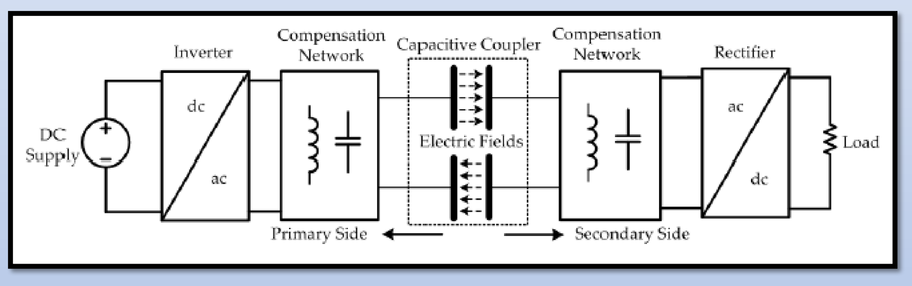

Figure 1. Typical structure of a capacitive power transfer system

This model includes auxiliary circuits and capacitive coupler. The auxiliary circuits are realized by power electronic converters and compensation networks. The capacitive coupler is performed by metal plates between the receiver and the transmitter. Two plates can be made with a coupling capacitance from a receiving terminal to a transmitter terminal.

Compensation circuit topologies have been created to resonate with the capacitive coupler and to generate high voltage.

CAPACITIVE COUPLER STRUCTURE

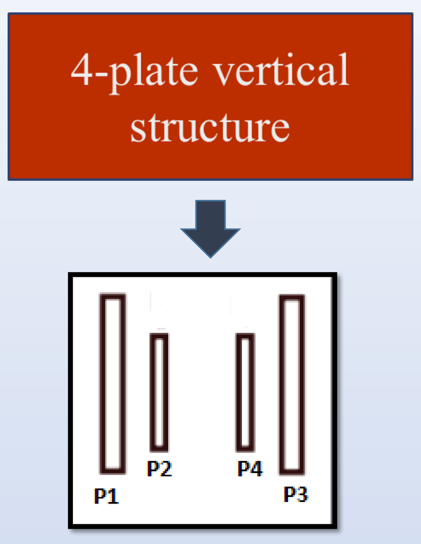

Figure 2. Capacitive coupler structure

LC COMPENSATION TOPOLOGY

- Used to resonate with the coupler.
- Provides high voltage on the plates to transfer high power.

Figure 3. LC compensation circuit

FULL BRIDGE INVERTER

- To provide the ac voltage for the resonant circuit.
- The output voltage of the full bridge inverter is Vo= 4Vdc/π.

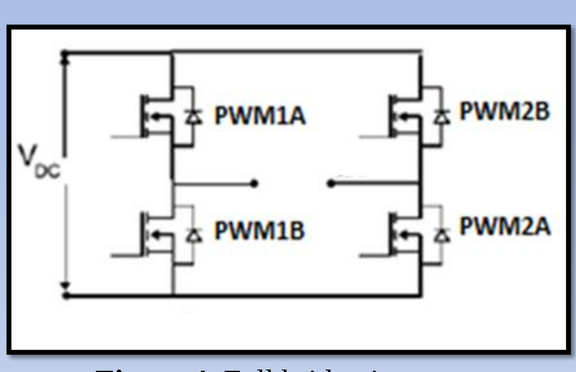

Figure 4. Full bridge inverter

EXPERIMENTAL SETUP

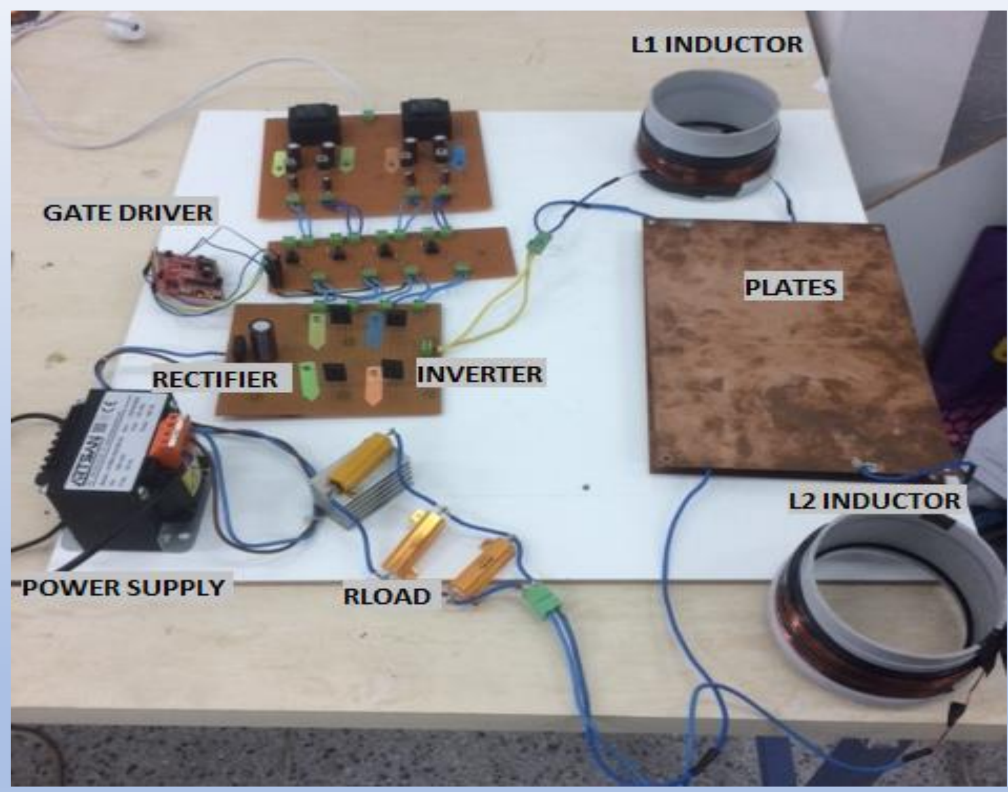

Figure 5. The prototype of capacitive power transfer system

PROTOTYPE DESIGN

DESIGNED PARAMETERS

All the circuit parameters was designed.

Table 1. System specifications and circuit parameters

PARAMETER	DESIGN VALUE	PARAMETER	DESIGN VALUE
V	38 V (peak)	C1	1.998 nF
l	20 cm	C2	1.998 nF
w	30 cm	L1	1.754 mH
tp	18 µm	L2	1.754 mH
dc	1.6 mm	f	85 kHz
d	1.5 cm	Cm	2.105 pF
Rload	12 Ω	kc	0.00105
R1	1.76 Ω	R2	1.76 Ω

EXPERIMENTAL RESULTS

MEASURED PARAMETERS

Table 2. Measured values and equivalent capacitances when well aligned

PARAMETER	MEASURED VALUE	PARAMETER	MEASURED VALUE
C13	58 pF	C14	60 pF
C24	68 pF	C23	57.2 pF
C12	2.279 nF	C34	2.279 nF
C1	2.34 nF	C2	2 nF
L1	1.731 mH	L2	1.746 mH
R1	1.746 Ω	R2	1.17 Ω
Cm	2 pF	kc	0.000924

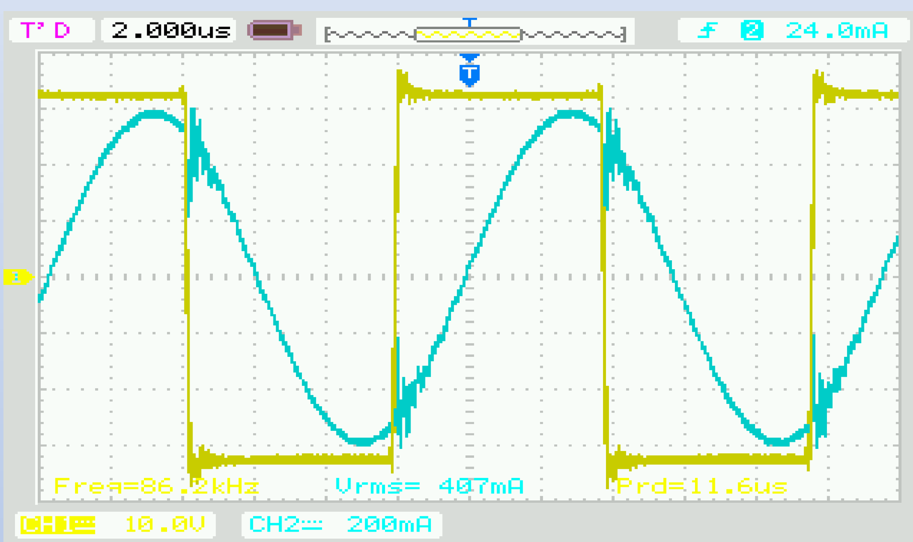

Figure 6. Experimental input voltage (V1) and current (I1) waveform

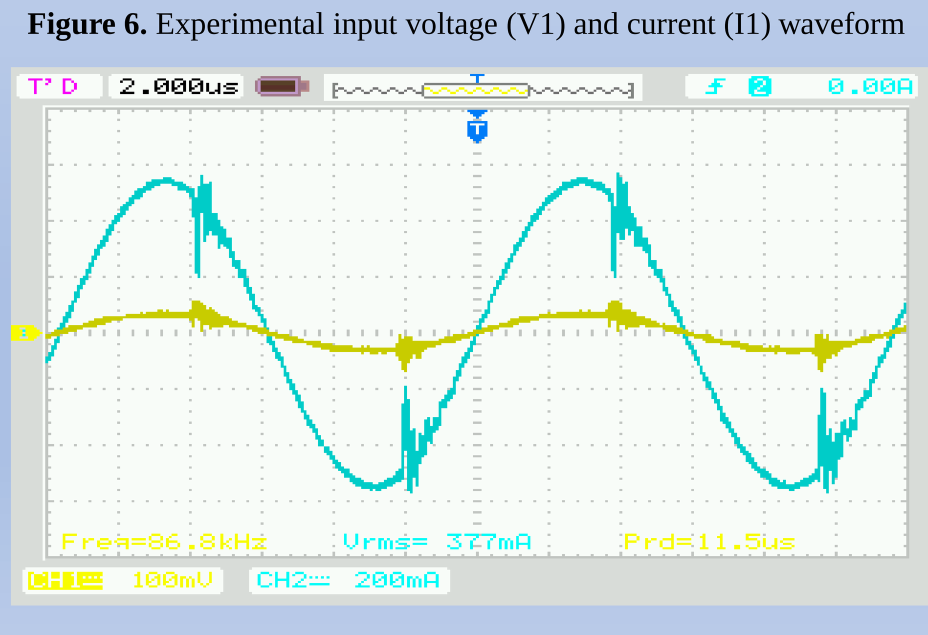

Figure 7. Experimental output voltage (V2) and current (I2) waveform

Pin (input power)	26.87 * 0.407 = 10.93 W
Pout (output power)	0.04 * 0.377 = 0.018 W

COMPARISON WITH DESIGNED PARAMETERS

The results obtained from the oscilloscope were compared with the measured parameters and the analysis results of the circuit established by the designed circuit parameters were compared.

Self capacitance values were obtained by creating a series RLC circuit at 94 kHz. As a result of the measurements, self-capacitance of the primary side was 2.34 nF. The capacitance value on the secondary side was 2 nF. As a result of these measurements, the primary side resonates at 78 kHz while the secondary side resonates at 85 kHz.

As a result of this situation, the efficiency and output power of the system is reduced. Because they have different operating frequencies, the working conditions in capacitive and inductive mode differ according to each other.

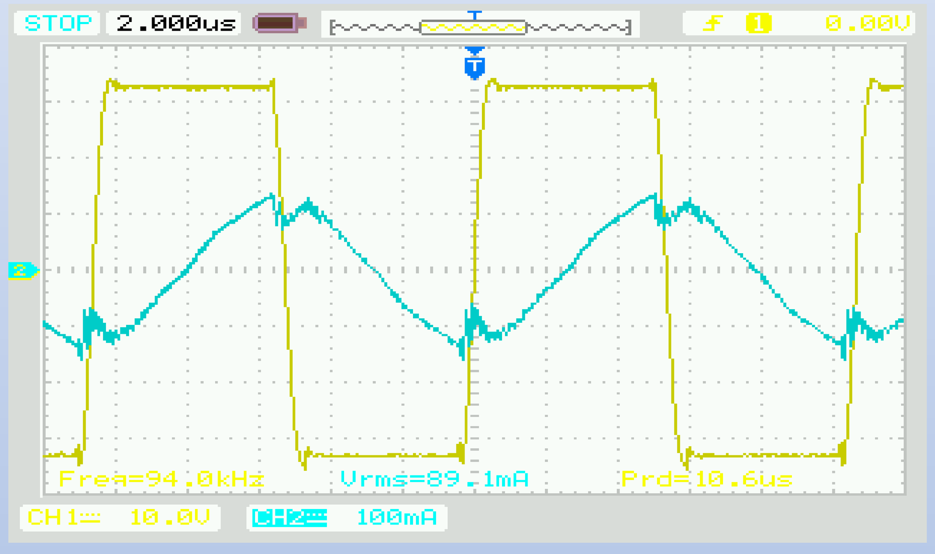

Figure 8. Current and voltage waveforms examined to measure C1 on primary

Figure 9. Current and voltage waveforms examined to measure C2 on secondary

CONCLUSIONS

In this project, the capacitive power transfer system using a four-plate coupler structure was designed for electric vehicle applications. Four plate vertical coupler structure with two plates on the receiver and transmitter side is designed. A prototype of the capacitive power transfer system has been designed and built to validate the proposed plate structure and compensation circuit topology.

According to the designed parameters and measured values, steady-state analysis was performed. The system was operated in inductive mode. The coupling coefficient is low. The mismatch condition has occurred in the circuit. Another factor affecting system efficiency is frequency resolution.

For better efficiency winding resistances can be reduced, the coupling coefficient can be increased and the system can be operated at resonance frequency.

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