Faculty of Electronics and Computer Engineering

DESIGN AND ANALYSIS OF CAPACITIVE POWER TRANSFER SYSTEM FOR LOW POWER APPLICATIONS

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DESIGN AND ANALYSIS OF CAPACITIVE POWER TRANSFER SYSTEM FOR LOW POWER APPLICATIONS

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DECLARATION

I declare that this entitled “Design and Analysis of Capacitive Power Transfer System for Low Power Applications” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : .....

Name : FARAH KHALIDAH BINTI ABDUL RAHMAN

Date : 28/7/2021

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Electronic Engineering.

Signature :.....

Supervisor Name : PROF MADYA DR MOHD SHAKIR B MD SAAT

Date : 1/8/2021

DEDICATION

To my beloved mother and father, Filzah and Harith, and the dedicated research team

ABSTRACT

Capacitive power transfer (CPT) system has been chosen as an alternative to perform the contactless power transfer in recent years. Advantages of CPT includes ability to confine electric field between coupling plates, power transfer capability through metal barriers, low eddy current power losses in metal surroundings, as well as the potential to minimise circuit size and costing. However, the challenge of handling CPT includes the separation distance between the transfer plates. This thesis focuses mainly on the development of a fundamental theory of CPT system and its application for low power contactless charging, starting from designing and analysing Class E resonant inverter to generating high frequency AC power source to drive the CPT system. The design is ensured to fulfil Zero-Voltage Switching (ZVS) condition in order to avoid switching loss. In electronic system, the quality factor, Q_L represents the effect of electrical resistance towards the system. By using Class E power amplifier circuit, the system with $Q_L = 10$ produced better results as compared to $Q_L = 40$. Considering the sensitivity of components variation, the investigation of Class E resonant inverter with π1a impedance matching circuit is done to act as a compensation network in order to enable efficient power transfer between the two parts of the system for wider load-range changes. The size of the capacitive plates was also succeeded to be reduced to half of the initial measurement by implementing the impedance matching network. The implementation of aluminium plate as transfer material for the CPT system shown the peak-to-peak value of output voltage is 25.5V with 52.55% duty cycle. After an impedance matching being inserted into the system, the experimental work produced 9.51W with 95.10% efficiency. Different materials of capacitive plates were also been investigated and discussed further in this thesis by providing the consequences of using particular materials towards the efficiency of the system. Copper has shown the best results by producing a better exponential decrease as compared to aluminium and zinc, in line graph of the output voltage.

REKA BENTUK DAN ANALISIS SISTEM PEMINDAHAN KUASA KAPASITIF UNTUK APLIKASI BERKUASA RENDAH

ABSTRAK

Sejak kebelakangan ini, pemindahan kuasa kapasitif (CPT) dipilih sebagai alternatif untuk proses pemindahan kuasa tanpa sentuh,. Kelebihan CPT termasuk daya pengehadan medan elektrik di antara plat gandingan, keupayaan memindah kuasa melalui halangan logam, kadar kehilangan kuasa arus pusar dalam persekitaran logam yang rendah, serta keupayaan untuk mengurangkan saiz litar serta kosnya. Walau bagaimanapun, cabaran bagi mengelolakan CPT termasuk dari segi jarak pemisahan antara dua plat. Tesis ini memberi tumpuan terhadap perkembangan teori asas sistem CPT dan aplikasinya untuk pengecasan tanpa wayar berkuasa rendah, bermula dengan mereka bentuk dan menganalisis litar penyongsang resonans Kelas E untuk menghasilkan sumber kuasa arus ulang-alik berfrekuensi tinggi untuk menggerakkan sistem CPT. Reka bentuk tersebut dipastikan memenuhi keadaan penukaran voltan sifar (ZVS) untuk mengelakkan kehilangan kuasa tukaran. Dalam sistem elektronik, faktor kualiti (Q_L) mewakili kesan rintangan elektrik terhadap sistem tersebut. Dengan menggunakan litar penambah kuasa Kelas E, sistem yang menggunakan Q_L = 10 menghasilkan keputusan yang lebih baik berbanding Q_L = 40. Mengambilkira variasi sensitiviti komponen, penyelidikan terhadap penyongsang resonans Kelas E dengan tambahan litar impedans π1a dilakukan, berfungsi sebagai rangkaian kompensasi demi membolehkan pemindahan kuasa yang efisien di antara dua bahagian dalam sistem tersebut untuk julat perubahan beban yang lebih luas. Saiz plat kapasitif juga berjaya dikurangkan sebanyak separuh daripada saiz yang asal dengan menambah litar padanan impedans ke dalam sistem sedia ada. Penggunaan plat aluminium sebagai bahan pindahan sistem CPT menghasilkan nilai voltan 25.5V puncak-ke-puncak dengan 52.55% kitaran tugas. Setelah litar penyesuaian impedans ditambah ke dalam sistem, eksperimen berjaya menghasilkan kuasa pengeluaran 9.51W bersamaan 95.10% kadar kecekapan. Penggunaan plat sentuh kapasitif daripada bahan berbeza juga telah dibincangkan di dalam tesis ini dengan menyatakan kesan penggunaan plat-plat yang berbeza tersebut. Plat daripada tembaga menghasilkan keputusan yang terbaik apabila menghasilkan penurunan eksponen yang lebih baik berbanding aluminium dan zink, dalam graf garis lurus untuk voltan output.

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LIST OF ABBREVIATIONS

AC	-	Alternating Current
AET	-	Acoustic Energy Transfer
APT	-	Acoustic Power Transfer
CPT	-	Capacitive Power Transfer
DC	-	Direct Current
FET	-	Field-Effect Transistor
FKEKK	-	Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
FRGS	-	Fundamental Research Grant Scheme
IPT	-	Inductive Power Transfer
LPT	-	Laser Power Transfer
MATLAB	-	Matrix Laboratory (Software)
MOSFET	-	Metal Oxide Semiconductor Field Effect Transistor
MPT	-	Microwave Power Transfer
PCB	-	Printed Circuit Board
PIC	-	Peripheral Interface Controller
PIM	-	Passive Impedance Matching
PLL	-	Phase-locked Loop
PWM	-	Pulse Width Modulator
RAGS	-	Research Acculturation Grant Scheme

RF	-	Radio Frequency
TV	-	Television
UTeM	-	Universiti Teknikal Malaysia Melaka
WPT	-	Wireless Power Transfer
ZCS	-	Zero-Current Switching
ZVS	-	Zero-Voltage Switching

LIST OF SYMBOLS

A	-	Area of capacitive plate
C	-	Capacitor
I	-	Current
d	-	Distance
D	-	Duty cycle
η	-	Efficiency
L	-	Inductor
P_i	-	Input power
Vi	-	Input voltage
P_o	-	Output power
Vo	-	Output voltage
π	-	Pi
Q_L	-	Quality factor
ε	-	Relative permittivity/dielectric constant of a material
R	-	Resistance
W	-	Watt

LIST OF PUBLICATIONS

The research papers produced and published during the course of this research are as follows:

1. **Rahman**, **F.K.A.,** Saat, S., Yusop, Y., Husin, H., and Aziz, Y., 2017. Design and Analysis of Capacitive Power Transfer System with and without Impedance Matching. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, 8 (3), pp.1260–1273.

2. **Rahman**, **F.K.A.,** Saat, S., Yusop, Y., Husin, S.H., and Ludin, S., 2017. Simulation-based Study of Capacitance Values Affected by Various Dielectric Materials and Distances for Low Power Wireless Power Transfer System. In: Malaysia Technical Scientist Association (MALTESAS), *Advancement Research in Circuits and Systems International Conference (ARECAS)*, Langkawi Island, Kedah, 20-22 Dec 2016. Malaysia.

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4. **Rahman**, **F.K.A.,** Saat, S., Zamri, L.H., Husain, N.M., Naim, N.A., and Padli, S. A., 2016. Design of Class-E Rectifier with DC-DC Boost Converter, *Journal of Telecommunication, Electronic and Computer Engineering (JTEC)*, 8 (1), pp.89–95.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Wireless power transfer (WPT) research has begun at the early 20th century. Yet, the progress of WPT researches has not been promising due to the lacking of applications that utilises wireless. Thus WPT ended prematurely, and not explored in detail. However, the advancements of technology have made WPT attracted high attention by many researchers in electronics field, especially, since the field is expanding widely. This is because wireless power transfer (WPT) technologies have been developed to supply power to the movable loads such as electric vehicles, implantable medical devices, mobile phones, and other applications without direct electrical contacts. This leads the applications become more flexible and portable.

In general, the wireless power transfer can be divided into three major types including inductive power transfer (IPT), capacitive power transfer (CPT), and the acoustic energy transfer (AET) as shown in Figure 1.1.