

**DEVELOPMENT OF CAPACITIVE POWER TRANSFER FOR
ROTARY APPLICATIONS**

NURUL NABILA BINTI MAMAT

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

**DEVELOPMENT OF CAPACITIVE POWER TRANSFER
FOR ROTARY APPLICATIONS**

NURUL NABILA BINTI MAMAT

**This report is submitted in partial fulfilment of the requirements
for the degree of Bachelor of Electronic Engineering with Honours**

**Faculty of Electronic and Computer Engineering
Universiti Teknikal Malaysia Melaka**

2018

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : DEVELOPMENT OF CAPACITIVE POWER
TRANSFER FOR ROTARY APPLICATIONS
Sesi Pengajian : 2017/2018

Saya NURUL NABILA BINTI MAMAT mengaku membenarkan laporan Projek Sarjana Muda ini disimpan di Perpustakaan dengan syarat-syarat kegunaan seperti berikut:

1. Laporan adalah hakmilik Universiti Teknikal Malaysia Melaka.
2. Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja.
3. Perpustakaan dibenarkan membuat salinan laporan ini sebagai bahan pertukaran antara institusi pengajian tinggi.
4. Sila tandakan (✓):

SULIT*

(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)

TERHAD*

(Mengandungi maklumat terhad yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan).

TIDAK TERHAD

Disahkan oleh:

(TANDATANGAN PENULIS)

(COP DAN TANDATANGAN PENYELIA)

Alamat Tetap: No. 26 Kedai
Pulai Chondong,
16600 Pulai
Chondong,
Kelantan

Tarikh : 01 Jun 2018

Tarikh : 01 Jun 2018

*CATATAN: Jika laporan ini SULIT atau TERHAD, sila lampirkan surat daripada pihak berkuasa/organisasi berkenaan dengan menyatakan sekali tempoh laporan ini perlu dikelaskan sebagai SULIT atau TERHAD.

DECLARATION

I declare that this report entitled “Development Of Capacitive Power Transfer For Rotary Applications” is the result of my own work except for quotes as cited in the references.

Signature :

Author : NURUL NABILA BINTI MAMAT

Date : 1 JUNE 2018

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 Bachelor of Electronic Engineering with Honours.

Signature :

Supervisor Name : PROF. MADYA DR. MOHD SHAKIR BIN MD SAAT

Date : 1 JUNE 2018

DEDICATION

To Allah and everyone who contributes towards this journey especially my parents.

ABSTRACT

Wireless power transfer (WPT), through the transmission of contactless energy, is not only being used for charging batteries in mobile devices, but it is also being increasingly used in the field of industrial applications. WPT by using capacitive approach (CPT) is introduced to enhance the convenience to the user. The proposed technique eliminates the use of connecting wire. A 10Watt wireless rotary CPT system is developed for applications having rotating parts such as a robot arm. To be specific, the capacitive based approach is utilized in this work because of its ability to transmit power through metal and in a metal surrounding environment where the inductive-based approach failed to perform. The project focuses on the coupling study of a rotary CPT application where the power supply is stationary while the load rotates and therefore allows the load to rotate 360 degrees free rotation. The Class E MOSFET power inverter is used in this project due to its ability to achieve high efficiency compared to other class of converters at high frequency. The prototype of the CPT for rotary application has also been successfully developed with disk plate thickness of 1mm-2mm. Overall, the developed CPT system for rotary application is able to deliver 5.5Watt with 83.33% efficiency. To enhance the power efficiency and ZVS conditions, a self-tuning circuit using phased-locked-loop has been proposed in this project. The efficiency of the simulation Class E without the self-tuning circuit is 96.83%. After the self-tuning circuit is added to transmitter part, the efficiency of the simulation is increased to 97%.

ABSTRAK

Pemindahan kuasa tanpa wayar (WPT), melalui penghantaran tenaga tanpa hubungan, tidak hanya digunakan untuk mengecas bateri dalam peranti mudah alih, tetapi juga semakin banyak digunakan dalam bidang aplikasi perindustrian. WPT dengan menggunakan pendekatan kapasitif (CPT) diperkenalkan untuk meningkatkan kemudahan kepada pengguna. Teknik yang dicadangkan menghapuskan penggunaan wayar penyambung. Sistem CPT berputar tanpa wayar 10Watt dibangunkan untuk aplikasi yang mempunyai bahagian berputar seperti lengan robot. Untuk lebih spesifik, pendekatan berasaskan kapasitif digunakan dalam kerja ini kerana keupayaannya untuk menghantar kuasa melalui logam dan dalam persekitaran sekeliling logam di mana pendekatan berasaskan induktif gagal dilaksanakan. Projek ini fokus kepada kajian gandingan aplikasi rotary CPT 10W di mana bekalan kuasa tidak bergerak sementara beban berputar dan dengan itu membolehkan beban berputar 360 darjah putaran bebas. Penukar kuasa kelas E MOSFET digunakan dalam projek ini kerana keupayaannya untuk mencapai kecekapan tinggi berbanding kelas penukar lain pada frekuensi tinggi. Prototaip CPT untuk aplikasi berputar juga telah berjaya dibangunkan dengan ketebalan plat cakera 1mm-2mm. Secara keseluruhannya, sistem CPT yang dibangunkan untuk aplikasi berputar mampu menghasilkan 5.5Watt dengan kecekapan 83.33%. Untuk meningkatkan kecekapan kuasa dan keadaan ZVS, litar penalaan diri menggunakan gelung berkunci berperingkat telah dicadangkan dalam projek ini. Kecekapan simulasi Kelas E tanpa litar penalaan diri adalah 96.83%. Selepas litar penalaan diri ditambah kepada bahagian pemancar, kecekapan simulasi ditingkatkan kepada 97%.

ACKNOWLEDGEMENTS

First and foremost, I would like to express my special thank and sincere gratitude to my project supervisor, Prof. Madya Dr. Mohd Shakir Bin Md Saat, for giving me an opportunity to exposed in this project, and also the moral supports and advises given throughout this project. I would also like to thank to Phd. students and Master students under Dr. Shakir who have lent their hands in assisting to complete the project.

Secondly, I would like to thank my beloved family members who always giving actuation and moral support to me throughout the whole studying life in UTeM and in this project.

The last but not least, I would also like to express my appreciation to all the technician, friends and all individuals that helped me throughout this Bachelor Degree Project 1 & 2 (PSM 1 & 2), which I have not mention their name. Without all of you, this project will not be finished successfully.

Thank you very much.

TABLE OF CONTENTS

Declaration	
Approval	
Dedication	
Abstract	i
Abstrak	ii
Acknowledgements	iii
Table of Contents	iv
List of Figures	viii
List of Tables	xii
List of Symbols and Abbreviations	xiii
List of Appendices	xiv
CHAPTER 1 INTRODUCTION	17
1.1 Project Background	17
1.2 Project Objective	20

1.3	Problem Statement	21
1.4	Scope Of Project	22
1.4.1	Development of Transmitter Plate	22
1.4.2	Materials	23
1.4.3	Development of Receiver Plate	23
1.4.4	Self-tuning Capacitive Power Transfer	23
1.5	Project Significance	25
1.6	Project Outline	26
	CHAPTER 2 LITERATURE REVIEW	27
2.1	Introduction of Wireless Power Transfer	28
2.1.1	Near-Field WPT	31
2.1.1.1	Inductive Power Transfer (IPT)	32
2.1.1.2	Capacitive Power Transfer (CPT)	34
2.1.1.3	Acoustic Power Transfer (APT)	38
2.1.2	Far-Field WPT	40
2.1.2.1	Laser Power Transfer (LPT) and Microwave Power Transfer (MPT)	40
2.2	Class E zero-voltage-switching (ZVS) Inverter	41
2.2.1	Zero Voltage Switching (ZVS)	43
	CHAPTER 3 METHODOLOGY	45
3.1	Project Methodology	45

3.2	Coupling Structure (CPT)	48
3.3	Class E inverter : Derivation of Equations	50
3.4	Series Capacitor	52
3.5	Receiver Circuit	53
3.6	Circuit Simulation : Class E Inverter circuit	54
3.7	Self-Tuning Using Phase Locked-Loop	56
3.8	Hardware Realization	59
3.8.1	Class E Inverter Circuit	60
3.8.1.1	Choke Inductor	60
3.8.1.2	Series Inductor	61
3.8.1.3	Shunt Capacitor	61
3.8.1.4	MOSFET	62
3.8.1.5	Load Resistor	63
3.8.2	MOSFET Driver	63
3.8.3	Transmitter and Receiver Disk Plate	64
3.8.4	Phase Locked-Loop	65
3.8.5	Receiver circuit	66
3.9	Fabrication Process	67
3.10	Prototype Construction	69
	CHAPTER 4 RESULTS AND DISCUSSION	72

4.1	Result	72
4.1.1	Simulation Result : Class E Inverter Circuit	72
4.1.2	Experimental Result: Class E Inverter Circuit	75
4.1.2.1	Distance analysis for CPT system	77
4.1.2.2	Misalignment analysis for CPT system	81
4.1.2.3	Simulation Result : Class E Inverter Circuit without PLL Circuit	84
4.1.2.4	Simulation Result : Class E Inverter Circuit with PLL Circuit	85
4.1.2.5	Prototype result	87
4.2	Discussions	88
4.3	Financial Expenses	90
CHAPTER 5 CONCLUSION AND RECOMMENDATION		91
5.1	Conclusion	91
5.2	Recommendation	93
REFERENCES		94

LIST OF FIGURES

Figure 1.1: Basic Diagram of Inductive Power Transfer	19
Figure 1.2: Basic Diagram of Capacitive Power Transfer	19
Figure 1.3 : The block diagram of CPT system for rotary applications	24
Figure 2.1: Nikola Tesla demonstrating WPT using capacitive coupling [11]	28
Figure 2.2: Actual rectenna used on the helicopter [13]	29
Figure 2.3: The block diagram of basic WPT system	30
Figure 2.4: General block diagram of IPT	32
Figure 2.5: Examples of commercially available inductive chargers [10]:	34
Figure 2.6: Basic configuration of a CPT system [3]	35
Figure 2.7: (a) An IPT system and (b) A CPT system with a metal barrier existing in the coupling part [21]	36
Figure 2.8: The architecture of APT system [14]	39
Figure 2.9: Class E ZVS inverter Circuit [15]	42
Figure 2.10: Class E switching inverter for optimum operation [15]	43
Figure 3.1: The flow chart in developing CPT system for rotary applications	47
Figure 3.2: The disk type coupling structure [3]	48

Figure 3.3: The cylindrical coupling structure [3]	49
Figure 3.4: The disk plate that has been used in this project	49
Figure 3.5: The prototype that will be used for rotary applications	50
Figure 3.6: Receiver circuit	53
Figure 3.7: Full Class E power amplifier circuit built in MATLAB Simulink	54
Figure 3.8: DC input current	55
Figure 3.9: ZVS condition of the simulation circuit	55
Figure 3.10: Output voltage and currents of the Class E simulation circuit	56
Figure 3.11: Phased-lock loop illustration [29]	57
Figure 3.12: Class E inverter with PLL circuit built in MATLAB Simulink	58
Figure 3.13: ZVS condition of the simulation circuit with the PLL circuit	58
Figure 3.14: Output voltage and currents of the Class E simulation circuit with PLL circuit	59
Figure 3.15: A toroidal through hole type	60
Figure 3.16: A radial type of the inductor	61
Figure 3.17: Tantalum capacitor type	62
Figure 3.18: MOSFET IRF510 packaging and it schematic symbol	62
Figure 3.19: Cement power resistors type	63
Figure 3.20: MOSFET driver packaging	63
Figure 3.21: MOSFET driver schematic circuit	64
Figure 3.22: The disk plate coupling for both transmitter and receiver	65
Figure 3.23: Essential components of a Phase-Locked Loop	65
Figure 3.24: Phase-Locked Loop schematic circuit	66

Figure 3.25: Receiver schematic circuit	67
Figure 3.26: Fabrication design a class E inverter circuit at Proteus 8 Pro	67
Figure 3.27: Fabrication design a MOSFET driver circuit at Proteus 8 Pro	68
Figure 3.28: Fabrication design a rectifier circuit at Proteus 8 Pro	68
Figure 3.29: Fabrication design a PLL circuit at Proteus 8 Pro	69
Figure 3.30: Overview of CPT system at rotary applications	69
Figure 3.31: MOSFET driver and Class E inverter circuit after fabricated	70
Figure 3.32: Receiver circuit that installed at rotating plate part	70
Figure 3.33: The PLL hardware based on schematic	71
Figure 3.34: Complete setup of CPT system in rotary applications	71
Figure 4.1: Waveform at gate of MOSFET	73
Figure 4.2: Waveform at drain of MOSFET	73
Figure 4.3: Waveform at drain and gate of MOSFET	74
Figure 4.4: Output voltage waveform before going into rectifier circuit	74
Figure 4.5: Waveform at gate MOSFET	75
Figure 4.6: Waveforms between MOSFET gate and MOSFET drain together	76
Figure 4.7: Waveform before rectified at the load	77
Figure 4.8: Experimental Waveforms of Receiver Plate Voltage, VRL, and Switch Voltage, VDS, at Different Coupling Plate Distances.	80
Figure 4.9: Graph of efficiency versus distance	80
Figure 4.10: The misalignment experiment.	81
Figure 4.11: Graph of efficiency versus misalignment distance	83
Figure 4.12: a) Actual ZVS condition for $C=2.17\text{nF}$	85

Figure 4.13: a) Actual ZVS condition for $RL=8.31\Omega$	86
Figure 4.14: Complete setup CPT system for rotary applications	87

LIST OF TABLES

Table 1.1: The specification of the project.	22
Table 3.1: Design specifications for Class E Inverter Circuit	46
Table 3.2: Comparison between calculation, simulation and practical values for the Class E power inverter	52
Table 4.1 : System Efficiency versus Distance	78
Table 4.2 : System Efficiency versus Misalignment distance	82
Table 4.3 : Financial Expenses for this project	90

LIST OF SYMBOLS AND ABBREVIATIONS

WPT	:	Wireless Power Transfer
IPT	:	Inductive Power Transfer
CPT	:	Capacitive Power Transfer
APT	:	Acoustic Power Transfer
MPT	:	Microwave Power Transfer
LPT	:	Light Power Transfer
ZVS	:	Zero Voltage Switching
DC	:	Direct Current
MOSFET	:	Metal Oxide Semiconductor Field Effect Transistor
PLL	:	Phase Locked-Loop
PWM	:	Pulse Width Modulation
IC	:	Integrated Circuit
UTeM	:	Universiti Teknikal Malaysia Melaka

LIST OF APPENDICES

Appendix A: Datasheet IRF510	100
Appendix B: Datasheet TC4422.....	107
Appendix C: Datasheet Diodes 1N4001.....	119
Appendix D: Datasheet toroidal inductor	121
Appendix E: Datasheet wirewound resistor	122

CHAPTER 1

INTRODUCTION

This chapter will briefly introduce the concept of wireless power transmission (WPT) for rotary applications using capacitive approach. The project background, project objectives, problem statement of the project, scope of work and the structure of report will also be included.

1.1 Project Background

Nowadays, wireless power transfer (WPT) technology has turned out to be one of the top research fields for its reliable applicability especially in low power applications such as phones charger, smart card system, high power electric vehicles (EV), and biomedical devices [1]. WPT is the transmission of electricity or energy

from a power source to an electrical load without the connecting wire, across an air gap [1]. WPT system would completely eliminate the existing high-tension power transmission line cables, towers and sub-stations between the generating station and consumers as well as facilitates the interconnection of electrical technology plants on a worldwide scale [3]. The advantages of WPT on cable elimination and maintenance-free operation are helpful especially for rotary applications to power up aside common electronic devices that we use every day [5].

The classification of WPT is divided into two categories that are near-field WPT and far-field WPT. Moreover, the near-field technique can be divided into three sections namely as inductive power transfer (IPT), acoustic power transfer (APT) and capacitive power transfer (CPT) [2]. In near-field power transfer, the IPT is using a coil that will produce the magnetic field to transfer power while CPT is using the capacitive plate that will produce an electric field to transfer power. Next, APT is using sound waves to wirelessly convey energy [2].

Nowadays, IPT is currently the most famous way to recognize wireless power transfer as shown in Figure 1.1. While IPT is a successful technique to transfer large power without metal contact, it has few disadvantages, such as magnetic field cannot pierce through metals [7]. For this project is more focuses on CPT system as shown in Figure 1.2 because due to many advantages. CPT system is a potentially convenient method based on the coupling capacitor approach, with the use of capacitor plate to come out with better EMI [3]. This CPT method is utilizing electric field rather than magnetic field used for the inductive approach which prone to misalignment disadvantages and the fact that it is unable to penetrate metal shielding as it will induce the eddy current in metal [25]. Since capacitive power transfer used the electric field coupling, it has been the key part for the new

improved method to achieve non-contact power transfer and gives greater effects onto the frequency, output power, and power efficiency of the system. This method can be the solution for drawback of the IPT system [2].

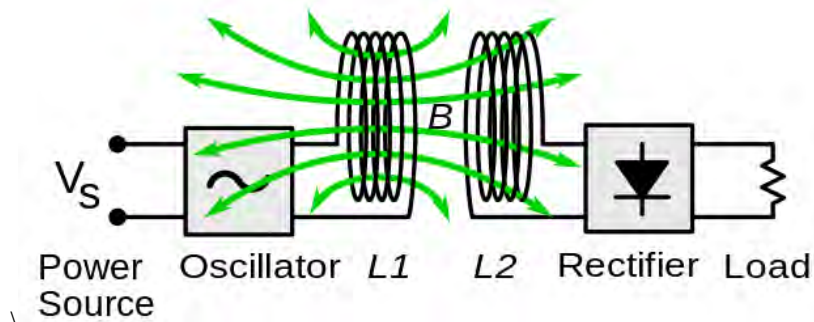


Figure 1.1: Basic Diagram of Inductive Power Transfer

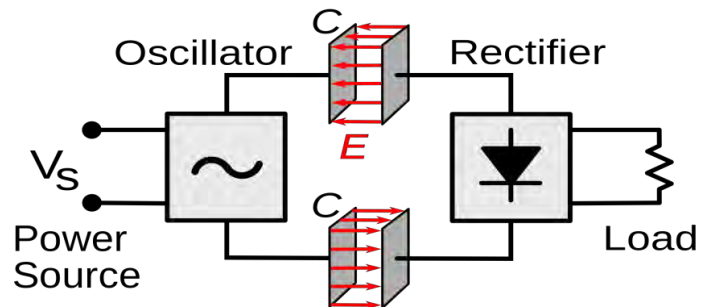


Figure 1.2: Basic Diagram of Capacitive Power Transfer

Wireless power transfer (WPT), through the transmission of contactless energy, is not only being used for charging batteries in mobile devices, but it is also being increasingly used in the field of industrial applications. WPT by using capacitive approach (CPT) is introduced to enhance the convenience to the user. The proposed technique eliminates the use of connecting wire. A 10W wireless rotary CPT system is developed for applications having rotating parts such as a robot arm.