THE DESIGN OF INDUCTIVE POWER TRANSFER FOR FISH AQUARIUM SYSTEM USING CLASS E INVERTER

RACHEL LEE KEI EN

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

2019

UNIVERSITI TEKNIKAL MALAYSIA MELAKA
FAKULTI KEJUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

BORANG PENGESAHAN STATUS LAPORAN
PROJEK SARJANA MUDA II

Tajuk Projek : THE DESIGN OF INDUCTIVE POWER TRANSFER FOR FISH AQUARIUM SYSTEM USING CLASS E INVERTER

Sesi Pengajian : 2018/2019

Saya RACHEL LEE KEI EN 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)

Alamat Tetap: 41, JLN BUKIT 16, BDR SERI ALAM 81750 MASAI, JOHOR

Tarikh : 31 MAY 2019

(COP DAN TANDATANGAN PENYELIA)

PROFESOR MADYA DR. MOHD SHAKIR BIN MD SAAT
Profesor Madya
Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya
76100 Durian Tunggal, Melaka

Tarikh : 31 MAY 2019

*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 "THE DESIGN OF INDUCTIVE POWER TRANSFER FOR FISH AQUARIUM SYSTEM USING CLASS E INVERTER" is the result of my own work except for quotes as cited in the references.

Signature : .....

Author : RACHEL LEE KEI EN.....

Date : 30/05/2019.....

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 : **DR. MOHD SHAKIR BIN MD SAAT**

Date : 30/5/19

ABSTRACT

Nowadays, the accessories in fish aquarium system such as water pump, internal filter, LED light and so on are powered using cables. By using cables will causes to safety issue such as wire might tangled, and risk of electric shock is high. Therefore, solving the problem by suggested wireless power transfer (WPT) technology to power up the accessories of the fish aquarium system. To be more specific, inductive power transfer (IPT) is used in this project compare to capacitive power transfer (CPT) due to more convenience and more safety. Class E inverter designed to convert the DC to AC. The inverter provides low switching loss because the project runs at high frequency, 1MHz operating frequency. Therefore, an IPT system with high efficiency which can power up two receivers at the same time by using Class E inverter for transmitter has been designed and fabricated. Impedance matching is added into receiver part enhance the efficiency of overall circuit. The analyses are done based on the distance between the coils and the misalignment of the coils against the output power and efficiency. The developed prototype is supplied at 24V in direct current and capable to deliver 5W power. The overall efficiency of the prototype is 87.81% which is higher than expected 60%.

ABSTRAK

Pada masa kini, aksesori dalam sistem akuarium ikan seperti pam air, penapis dalaman, cahaya LED dan sebagainya dihidupkan menggunakan kabel. Dengan menggunakan kabel akan menyebabkan isu keselamatan seperti wayar mungkin kusut dan risiko kejutan elektrik tinggi. Oleh itu, menyelesaikan masalah dengan teknologi pemindahan kuasa tanpa wayar (WPT) yang dicadangkan untuk menghidupkan aksesori sistem akuarium ikan. Untuk menjadi lebih spesifik, pemindahan kuasa beraruhan (IPT) digunakan dalam projek ini berbanding dengan pemindahan kuasa kapasitif (CPT) kerana lebih banyak kemudahan dan lebih banyak keselamatan. Kelas E inverter direka untuk menukar DC ke AC. Inverter menyediakan kehilangan beralih rendah kerana projek ini berjalan pada frekuensi tinggi, kekerapan operasi 1MHz. Oleh itu, IPT yang mempunyai kecekapan tinggi yang dapat membekalkan dua penerima pada masa yang sama dengan menggunakan inverter Kelas E. pencocokan impedans ditambah ke bahagian penerima untuk meningkatkan kecekapan litar keseluruhan. Analisis dilakukan berdasarkan jarak antara gegelung dan misalignment gegelung terhadap kuasa output dan kecekapan. Prototaip yang dihidupkan pada 24V dalam arus langsung dan mampu menyampaikan kuasa 5W. Kecekapan keseluruhan prototaip adalah 87.81% yang lebih tinggi daripada jangkaan 60%.

ACKNOWLEDGEMENTS

I am grateful to God because without His will, I would not be able to manage this project well on the expected date in good condition. I would like to use this chance to express my gratitude to my supervisor, Dr. Mohd Shakir Bin Md Saat for his willingness to spend his time to give guidance and consultation whenever I needed. Next, I would share my thanks to my beloved family especially to my parents for their encouragement and support so that I can push myself to the limit. Besides that, I would like to express my gratitude to my friends, who are under supervised by Dr. Shakir that send help, shared knowledge and work together to achieve the project. I also place on record, my sense of gratitude to one and all, who directly and indirectly, have lent their hand in the journey.

TABLE OF CONTENTS

Declaration

Approval

Dedication

Abstract i

Abstrak ii

Acknowledgements iii

Table of Contents iv

List of Figures vii

List of Tables ix

List of Symbols and Abbreviations x

List of Appendices xi

CHAPTER 1: INTRODUCTION 1

1.1 Project Background 1

1.2 Project Objectives 2

1.3 Problem Statement 3

1.4 Scope of Work 4

1.5 Overview of Methodology 5

1.6 Project Outline 6

CHAPTER 2: Literature review **7**

2.1 Wireless Power Transfer 7

2.2 Acoustic Power Transfer (APT) 9

2.3 Capacitive Power Transfer (CPT) 10

2.4 Inductive Power Transfer (IPT) 12

2.5 Class-E Inverter 13

2.6 Zero Voltage Switching (ZVS) 15

2.7 Impedance Matching 17

CHAPTER 3: METHODOLOGY **19**

3.1 Process Flow of the Project 19

3.2 Block Diagram 21

3.3 Circuit Design of Class-E Inverter 22

3.4 Impedance Matching 24

3.5 MOSFET Driver 25

3.6 Design Transmitter, Tx and Receiver, Rx Coils 25

3.7 Circuit Design of Rectifier with Impedance Matching 28

3.8 Performance Analysis 29

3.9 Software used 30

CHAPTER 4: RESULTS AND DISCUSSION **32**

4.1 Analysis of Class-E Inverter 32

4.1.1 Simulation Result 33

4.1.2 Experimental Result 35

4.2 MOSFET Driver 38

4.3 Design of Transmitter, Tx and Receiver, Rx coils 39

4.4 Rectifier Module 41

4.5 Performance Analysis 43

4.5.1 Analysis the Distance between Transmitter and Receiver coils 43

4.5.2 Analysis the output power based on misalignment distance 45

4.6 Development of project prototype 47

4.7 Expenses 50

CHAPTER 5: CONCLUSION AND FUTURE WORKS **51**

5.1 Overview 51

5.2 Conclusion 51

5.3 Recommendation 52

REFERENCES **54**

APPENDICES **58**

CHAPTER 4: RESULTS AND DISCUSSION **32**

4.1 Analysis of Class-E Inverter 32

4.1.1 Simulation Result 33

4.1.2 Experimental Result 35

4.2 MOSFET Driver 38

4.3 Design of Transmitter, Tx and Receiver, Rx coils 39

4.4 Rectifier Module 41

4.5 Performance Analysis 43

4.5.1 Analysis the Distance between Transmitter and Receiver coils 43

4.5.2 Analysis the output power based on misalignment distance 45

4.6 Development of project prototype 47

4.7 Expenses 50

CHAPTER 5: CONCLUSION AND FUTURE WORKS **51**

5.1 Overview 51

5.2 Conclusion 51

5.3 Recommendation 52

REFERENCES **54**

APPENDICES **58**

LIST OF FIGURES

Figure 1.1: The illustration of the project. 4

Figure 1.2: The steps in finishing the project..... 5

Figure 2.1: The typical structure of Wireless Power Transfer system. 8

Figure 2.2: The Sonicare electric toothbrush by Philips. 9

Figure 2.3: The basic structure of APT system. 10

Figure 2.4: The basic structure of the CPT system. 11

Figure 2.5: The basic structure of the IPT system. 12

Figure 2.6: The structure of Class-E inverter. 14

Figure 2.7: The hard switching condition for the MOSFET that might give a huge of switching losses. 16

Figure 2.8: The perfect Zero-voltage switching. 16

Figure 2.9: The circuits of the π1a, π2a, π1b, π4a, four type of impedance matching networks. 17

Figure 2.10: Class-E with LCCL matching network circuit. 18

Figure 3.1: The flowchart of the project. 20

Figure 3.2: The block diagram of the project. 21

Figure 3.3: The basic components for Class-E inverter. 22

Figure 3.4: The circuit of MOSFET driver. 25

Figure 3.5: The design of transmitter coil. 26

Figure 3.6: The design of receiver coil. 27

Figure 3.7: The design of the rectifier. 29

Figure 3.8: Simulink page. 30

Figure 3.9: Proteus design suite 8.0 page. 31

Figure 3.10: LC Resonance Calculate page. 31

Figure 4.1: The class-E inverter circuit is stimulated in MATLAB Simulink. 33

Figure 4.2: The simulation waveform got the V_{gs} and V_{ds} at 1MHz. 34

Figure 4.3: The simulation waveform for the Vo and Io. 34

Figure 4.4: The experimental setup of class-E inverter on breadboard. 36

Figure 4.5: Experimental waveform for ZVS at 1MHz. 37

Figure 4.6: Experimental waveforms for output voltage and output current. 38

Figure 4.7: The MOSFET driver output waveform. 39

Figure 4.8: The design of transmitter coil, Tx. 40

Figure 4.9: The design of receiver coils, Rx. 41

Figure 4.10: Receiver part for DC water pump. 42

Figure 4.11: Receiver part for LED light. 43

Figure 4.12: The graph of efficiency based on the distance between transmitter and receiver. 45

Figure 4.13: The graph of output power based on the misalignment distance of receiver coil. 47

Figure 4.14: The printed circuit board (PCB) fabrication of transmitter circuit. 48

Figure 4.15: The PCB fabrication of receiver circuit for LED light. 48

Figure 4.16: The PCB fabrication of receiver circuit for DC water pump. 49

Figure 4.17: The completed prototype. 49

LIST OF TABLES

Table 3.1 The loads specifications. 28

Table 4.1: Class-E inverter simulation result. 33

Table 4.2: Class-E inverter experimental result. 36

Table 4.3 Design specification of Transmitter and Receiver coils 41

Table 4.4 Analysis the distance between transmitter and receiver. 44

Table 4.5 The misalignment of the receiver. 46

Table 4.6 Unit price of the required components and electronic appliances 50

LIST OF SYMBOLS AND ABBREVIATIONS

WPT	:	Wireless Power Transfer
IPT	:	Inductive Power Transfer
CPT	:	Capacitive Power Transfer
Tx	:	Transmitter
Rx	:	Receiver
DC	:	Direct Current
AC	:	Alternating Current
ZVS	:	Zero Voltage Switching
ZVDS	:	Zero Voltage Derivative Switching

LIST OF APPENDICES

Appendix A: MOSFET IRF 640 59

Appendix B: MOSFET Driver TC 4422 67

Appendix C: Diode UF 3008 81

CHAPTER 1:

INTRODUCTION

The first chapter explains about project background, project objectives, problem statement of the project, scope of work, overview of methodology and lastly project outline.

1.1 Project Background

Wireless Power Transfer is a transmission of electrical or electromagnetic energy from power supply to load without direct contact between metals. By having this technology, cables and connectors are eliminated in circuits. This leads to increase the reliability and maintenance-free operation. In 1890s, Nikola Tesla is the first person that demonstrated wireless power transfer [1]. He powered up 25 fluorescent lamps on the street without using the connectors. The one of the advantages of WPT

are maintenance free operation which are helpful for underwater electronics devices to power up aside common electronics devices.

Thus, WPT is classified into two categories which are near-field and far-field. For near-field power transfer, inductive power transfer (IPT) is the most common in real world compared to capacitive power transfer (CPT) and acoustic power transfer (APT). Besides IPT, CPT and APT, light power transfer (LPT) and microwave power transfer are under far-field power transfer. For this project, WPT is applied in the fish aquarium. To be more specific, IPT is chosen to transfer power to the fish aquarium system.

Currently, the fish aquarium system is powered up using cables or wires. Safety issue that caused by using cable such as cables might tangled, and the risk of electric shock is high. IPT is proposed to solve this problem by eliminate the cables. The IPT fish aquarium system is powered up wirelessly which means without any connection between power supply and load. IPT system transfer the power in electromagnetic field.

1.2 Project Objectives

The Objectives of this project are listed as follows:

a. To design Class E Inductive Power Transfer for fish aquarium system.
b. To propose a suitable impedance matching circuit in order to improve efficiency of the proposed IPT system.

c. To analyze the performance of developed fish aquarium's prototype based on the output power and efficiency.

1.3 Problem Statement

Statement 1:

The accessories in fish aquarium system such as water pump and filter are powered up using cables may leads to safety issue as wire might be tangled. Thus, wireless power transfer technology will be suggested to power up the fish aquarium.

Statement 2:

By using Capacitive Power Transfer can reducing the interference between the capacitor plates. However, CPT has lower transfer capacity due to the frequency of CPT is more difficult to improve in the actual system. Therefore, Inductive Power Transfer are more suitable for this project due to having higher power transfer capacity.

Statement 3:

IPT are convenience but still having shortage such as misalignment between the coils and switching losses. Misalignment and switching losses will cause the reduction of the efficiency of the whole system. Thus, impedance matching and class E inverter are proposed to overcome the problem by maximizing the power transfer and minimizing the switching loss.

1.4 Scope of Work

The scope of work for this project are as follows:

a. The input power for this work is 15 W. The selection is made based on 60% of the power that power up the load from the reference.

b. The minimum output power is set to be at least 9W as the efficiency is expected to be more than 60%

c. The current that supply through the load is lower than 1A, which calculated by using the voltage and power stated on the load reference.

d. The size of aquarium is 26cm(L)x19cm(W)x32cm(H).

e. The illustration of the project is given in Figure 1.1.

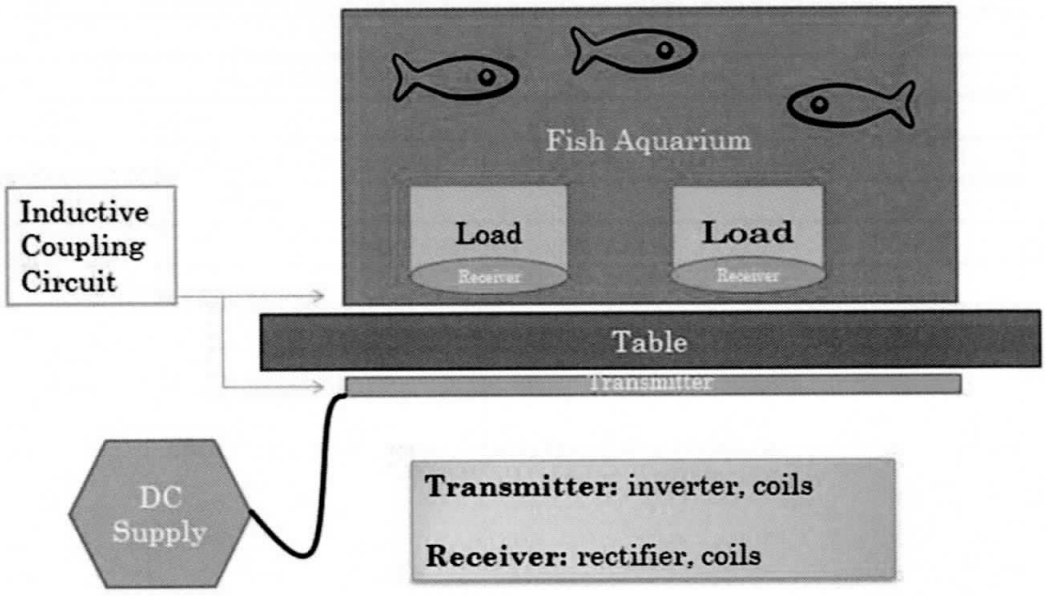

Figure 1.1: The illustration of the project.

1.5 Overview of Methodology

There are several steps to complete this project. The first step is designing circuit by calculating the components values based on the desired requirement. Next, construct the designed circuit with calculated values in simulation software such as SimuLink. Third step is testing the circuit in breadboard with available component values which nearest to the calculated values. Next step is to fabricate the circuit in PCB and assembly the components. Troubleshooting the circuit is the following step. The last step is to analyze the performance of prototype and compare with the simulation result. Figure 1.2 illustrates the steps in finishing the project.

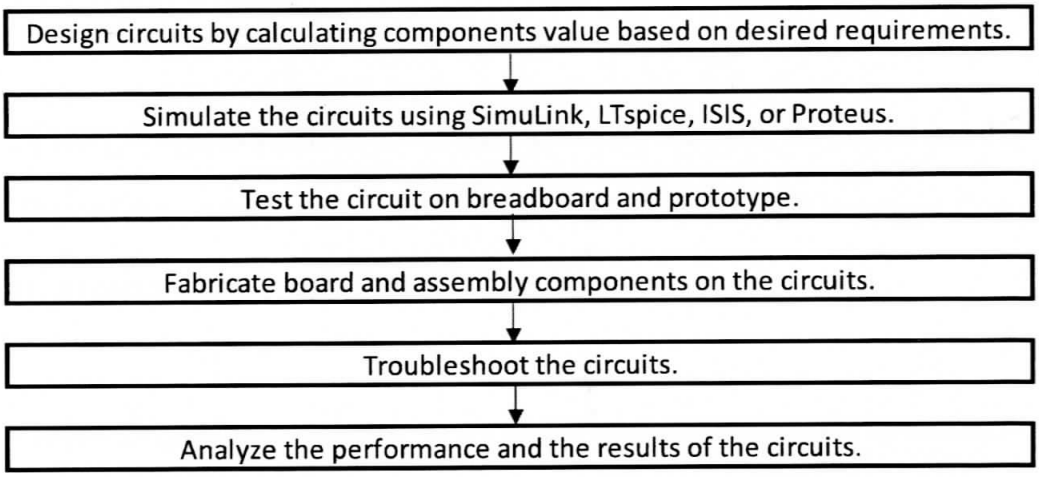

Figure 1.2: The steps in finishing the project.

1.6 Project Outline

Chapter I, the chapter introduces the project background, the project objectives, the problem statements of project, the scope of work as well as project outline. This chapter provides a clearer view to the reader on the purpose of the project and briefly explain the thesis.

Chapter II is all about the literature review of the project. This chapter covered with the previous researches by other researchers. The researches included wireless power transfer (WPT), inductive power transfer (IPT), capacitive power transfer (CPT), class E inverter and zero voltage switching (ZVS).

Chapter III explains the methodology that used to complete the project and the process flow of the project. The techniques that used to complete this project from theoretical to experimental are explained in this chapter.

Chapter IV performs the result on simulation and experimental. The achieved results are discussed and analyzed and the expenses for the project also briefly explained.

Chapter V concludes the project based on the result achieved and objectives targeted. Recommendation on future works or improvements are suggested also part of this chapter.

CHAPTER 2:

LITERATURE REVIEW

For the second chapter, previous researches by other researchers that are related to the project are explained and discussed. Background of Wireless Power Transfer (WPT), Inductive Power Transfer (IPT), Capacitive Power Transfer (CPT). Class E inverter and Zero Voltage Switching are briefly explained in this chapter.

2.1 Wireless Power Transfer

Wireless Power (WPT) is a transmission of electrical or electromagnetic energy from a power supply to a load without using wires. WPT has become more attractive topic to be explored as it is popular in the power transmission system [2]. WPT leads the movement of devices more flexible. Transmitter connected to power

supply, which converts the power to a time-varying electromagnetic field or electric field, and the receiver which receive the power and convert it back to DC or AC electric current used by an electrical load. Figure 2.1 is a typical structure of a WPT system[3].

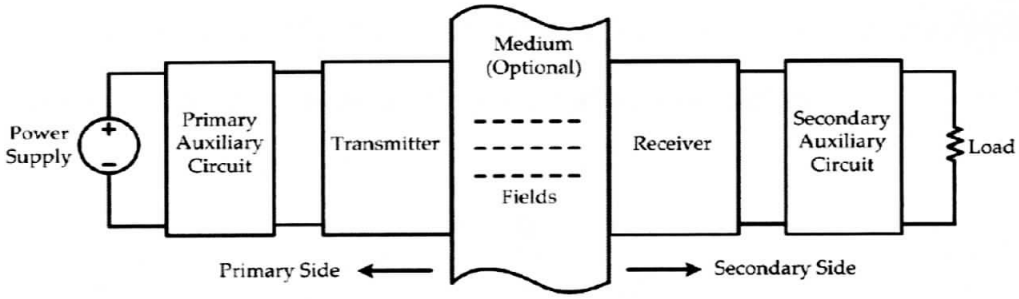

Figure 2.1: The typical structure of Wireless Power Transfer system.

Articles in [4]describe advantages and disadvantages of WPT in their articles. Ones of the advantages of WPT is power transmission line cables are eliminated between supply and load. After the cables are eliminated, the risk of electric shock can be reduced. The losses of power transmission can be ignored due to the elimination of cables. Thus, the efficiency in theoretically is expected to be higher than wired transmission. The cost of electrical energy is reduced since no resistance in wireless transmission and the cost for power transmission and distribution will become lesser. On top of that, places that are difficult to reach with cables can be reach easily by using WPT system. The freedom in making choice of transmitter and receiver in the system are more varied for WPT system.

Some other examples of WPT applications can be prove in [5][6]. In 2016, IKEA has released a new table that able to charge electronics gadgets by placing at certain spot [5]. Besides that, Philips also released a device which applied WPT,