THE DEVELOPMENT OF WIRELESS POWER TRANSFER TECHNOLOGIES FOR LOW POWER APPLICATIONS: AN ACOUSTIC BASED APPROACH

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This Report Is Submitted In Partial Fufillment Of Requirement For The Bachelor of Degree of Electronic Engineering (Wireless Communication)

Fakulti Kejuruteraan Elektronik dan Kejuruteraan Komputer
Universiti Teknikal Malaysia Melaka

JUNE 2015

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FAKULTI KEJURUTERAAN ELEKTRONIK DAN KEJURUTERAAN KOMPUTER

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ACKNOWLEDGEMENT

In the name of Allah, the most Compassionate, the most merciful.

In the opportunity, I would like to express the deepest appreciation to respected supervisor, Dr. Mohd Shakir Bin Md. Saat who has helped us throughout this project with his invaluable advice and thoughts. His great knowledge is very resourceful and we are very impressed with his magnanimity.

Also, my gratitude extends to all staff of Faculty of Electronic and Computer Engineering, especially to Electronic And Computer Engineering lectures for their advices and ideas in bettering the approach. Appreciation goes to of the post-graduate friends for providing decent suggestions and necessary information during the completion of this report.

Last but not least, I would like to thank my family and also my engineering colleagues for their encouragement, invaluable support and suggestions given to improve this project. Thank you again and may Allah bless you all.

ABSTRACT

Wireless power transfer (WPT) is the transmission of electrical power across a medium without the use of electrical conductors. There is three major type of WPT which are Acoustic Power Transfer (APT), Inductive Power Transfer (IPT) and Capacitive Power Transfer (CPT). Between these, the APT has the advantages of such as can be used where the EM fields are not allowed, and the efficiency of APT is much higher compared to IPT in terms of greater distance transfer power range and different medium of transfer i.e (body tissue, water, air, etc). Due to this fact, for this project the acoustic method has been considered. This project aims to transfer low power wirelessly by using the acoustic based method. The feasibility of transmitting electric power through some specific surface or material by propagating acoustic waves using piezoelectric transducers was analysed. The efficiency of power transmission for APT has been briefly examined at the different transmission medium. For this project, the metal block and air were chosen as the transfer medium and the efficiency performance of these medium have successfully been analyzed. In the end, a prototype of APT system was developed which was capable of transferring voltage through air at the maximum distance of 10cm at 0.96V. The performances analyses of the developed prototype are discussed and the future recommendation of this method is also presented.

Keywords: Acoustic Power Transfer (APT), low power small scaleprototype, wireless power transfer (WPT)

ABSTRAK

Pemindahan kuasa tanpa wayar (Wireless power transfer) adalah penghantaran kuasa elektrik di mana tanpa menggunakan sebarang konduktor elektrik atau kable. Terdapat tiga jenis kaedah dalam Wireless power transfer yang sering digunakan adalah kaedah berasaskan Akustik (Acoustic Power Transfer), keadah berasaskan induktif (Inductive Power Transfer) dan kaedah berasaskan kapasitif (Capacitive Power Transfer). Di antara kaedah-kaedah itu, kaedah APT mempunyai kelebihan seperti boleh digunakan di mana medan electromagnetic tidak dibenarkan, dan kecekapan kaedah APT adalah lebih tinggi berbanding dengan keadah IPT dari segi jarak permindahan kuasa yang lebih jauh. Berdasarkan kenyataan ini, kaedah APT telah dipertimbangkan. Projek ini bertujuan untuk memindahkan kuasa yang rendah secara tanpa wayar dengan menggunakan kaedah APT. Di dalam kaedah APT ini, Kuasa elektrik di hantar melalui beberapa permukaan tertentu atau bahan dengan menyebarkan gelombang akustik menggunakan transduser piezoelektrik dianalisis. Kecekapan penghantaran kuasa untuk kaedah APT telah dikaji di media penghantaran yang berbeza. Untuk projek ini, blok logam dan udara telah dipilih sebagai medium pemindahan dan prestasi kecekapan pemindahan kuasa ini dianalysis dan telah ditunjukkan. Akhirnya, satu prototaip sistem APT telah dibangunkan yang mampu memindahkan voltan melalui udara pada jarak maksimum 10cm di 0.96V. Analisis pada prototaip yang dibangunkan dibincangkan dan cadangan untuk masa depan juga dibentangkan.

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LIST OF ABBREVIATION

WPT	-	Wireless Power Transfer
IPT	-	Inductive Power Transfer
CPT	-	Capacitive Power Transfer
APT	-	Acoustic Power Transfer
ZVS	-	Zero Voltage Switching

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CHAPTER I

INTRODUCTION

This chapter explains the overview of this project entitled “Developing acoustic power transfer based approach through different transmission medium for low power application”. Background study, problem statement, objective and also scope of work are discussed in the succeeding segments.

1.1 Project Introduction.

Wireless power transfer has been studied over years since Nikola Tesla demonstrated wireless illumination of phosphorescent lamp in 1893AD.Since then, magnetic induction has been studied and hence produced wireless chargers for devices these days. Since then, a lot of works have been devoted in this framework and they are discussed in the following text.

1.1.1 Wireless Power Transfer (WPT).

Wireless Power Transfer (WPT) is the transmission of electrical energy from a power source to an acquiring appliance without having to use solid wire connections or even conductors [1-4]. This innovative technological generates new alternatives to provide mobile devices with electrical energy. Due to that facts, the

WPT system is elimination of cables, connectors and slip-rings to improve the dependability and maintenance-free operating of such an important systems as in aerospace, biomedical, multi sensors and robotics applications.

Figure 1.1 presents the basic classification of the WPT systems. The WPT system can be divided according to the medium transfer used for power transmission, which are acoustic-based, capacitive-coupling, inductively coupling and light-based.

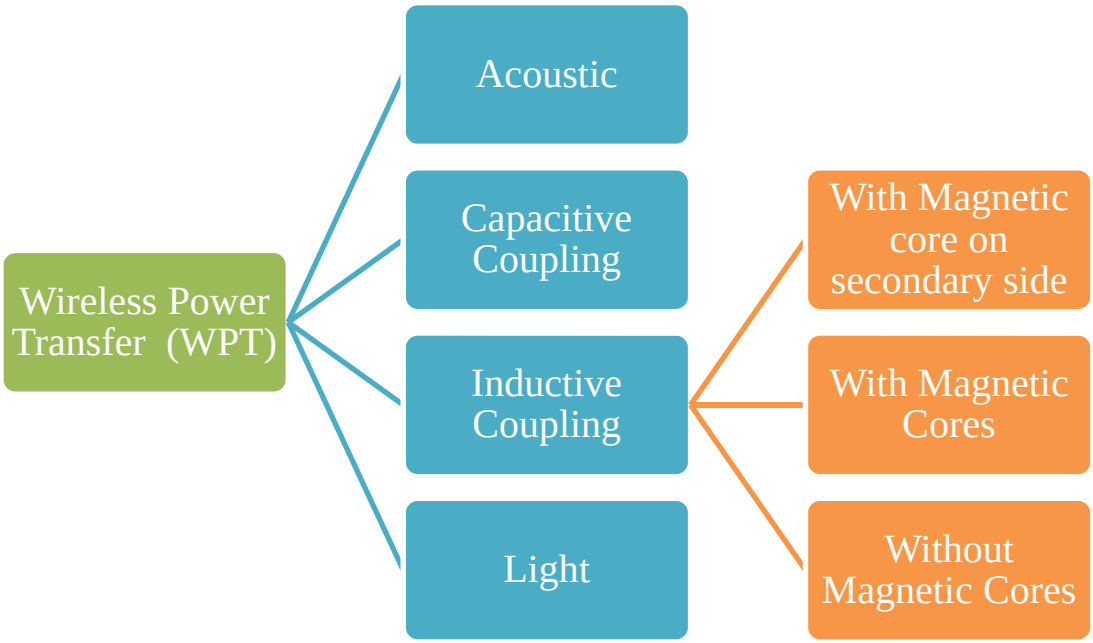

Figure 1.1: Classification of WPT [2].

The most widely used method in the WPT is inductive coupling between transmitter and receiver which has been widely applied to most of the devices. The idea about the IPT is the energy is transferred to the receiver by electromagnetic induction through the use of inductive coupling.

However, there exists a major significant disadvantage of IPT that is the efficiency of energy transmitting relies upon the transmission distance. The Acoustic Power Transfer (APT) is optimizing the vibrations or ultrasonic propagation wave as an alternative to electromagnetic fields for energy transmission.

1.1.2 Project Overview.

Acoustic Power Transfer (APT) is one of the techniques in power electronics based Wireless power transfer (WPT). The APT is the process where Electrical energy is delivered via power electronic circuit and it is converted by a transmitter transducer into an acoustic wave. Than the wave are propagates via medium (i.e: air, living tissue, metal or other wall, etc.). A receiver transducer is positioned at a point along the path of the sound wave for the inverse process of converting back the motion that is created by the sound wave into electrical power. A rectifier provides a usable steady DC voltage that drives a load. The medium can be anything ranging from air to human tissue or a solid wall. Any material that will propagate a pressure wave can be used as a medium. [1-3].

Maintenance and environment conditions are important factors in designing systems for material handling and transportation applications, for instance automotive assembly, storage and retrieval logistics and sorting. Typical applications |which was able to benefit from WPT include things like overhead trolleys, conveyor trolleys, guided floor conveyors, push-skid conveyors, storage and retrieval units, Pallet transportation systems, baggage handling, panel gantries, elevator equipment, amusement park rides and lastly, battery charging stations. The WPT is ideal application where the mobile equipment has to cover long distances. Secondly, a variable, extendable track layout is required. Thirdly, additional environmental are not permitted in sensitive area. Lastly, the operation takes place in wet and humid area.[2-3].

As for the APT techniques can be used at the various applications. As an example applications that used APT are ultrasonic cleaning, medical ultrasonography, distance measurement, therapeutic ultrasonic and etc. These applications of APT are that they directly use the acoustic energy to achieve a specific goal, without converting it back to electrical energy. [2]

Piezoelectric energy harvesting and piezoelectric transformers are relatedly close to APT. Energy harvesters make use of available vibrational energy to generate electricity and could be considered to be a non-driven APT system. Piezoelectric

transformer converts electric energy into vibration, with the inverse process taking place at the secondary side. This is the essence of APT. However, it lacks the spatial separation of the transmitter and receiver that is desired for WPT system.

1.1.3 Motivation.

As wireless and portable mobile devices become pervasive, charging batteries for these devices has become a critical problem. Existing battery charging technologies are dominated by wired technology, which requires a wired power plug to be connected to an electrical wall outlet. The WPT is also useful in situations where the use of wires is impossible, dangerous, or inconvenient. APT has an advantages can be transferring power through different medium example water, metal, concrit wall and etc. by using a suitable transducer. Compared to IPT and CPT has obstacle constraintsdue to EM field. As can be seen , now days diversity of technology in some parts of fields such as medical , marine and industry has some constraints when in situation with the transfer of energy use in devices appliances. Therefore, in this project, an acoustic based method power transfer is suggested.

1.2 Problems Statement.

Nowadays, wireless power transfer (WPT) systems become more widely developed. This innovative technology brings about new possibilities of supplying mobile devices with electrical energy by allowing elimination of cables, connectors, and/or slip rings. This increases reliability and maintenance-free operation of such systems in critical applications such as aerospace, biomedicine, multisensory, and robotics. The most popular WPT method is inductive and capacitive. However, the Inductive power transfer (IPT) and capacitive power transfer (CPT) have the limitation such as short distance and cannot be propagate the power via medium. This problem could be overcome by using APT methods. However, a major problem with the APT method is the low efficiency power during the power transfer process. The transmitter part of APT system enables high power transmission. But, at the receiver part of APT system has lower capability of power transmission and

therefore it reduces the efficiency power significantly. To make improvement to this problem is by using a Class E amplifier in the circuit so that the power towards the load can be enhanced and amplify efficiently.

1.3 Objective.

The objectives of this project are:

a) To develop a prototype of APT system for low power applications.
b) To design a compensation circuit to improve the efficiency of such circuit.
c) To analyse performance of APT system for different type of transmission medium, (i.e: air and metal)

1.4 Scope of Work.

This prototype is designed in a small scale low power and has a specification as below:

a) Frequency resonant around : 20kHz~ 40kHz
b) Range (Distance coverage) : 1 cm ~ 10 cm
c) Low Power Transfer usage: 7mW
d) efficiency up to about 40%

A push-pull converter or Class-E amplifier is used at the transmitter to convert DC to AC. Rectifier circuit will be used at receiver transducer. The diagram below show how the APT system in Schematic designs:

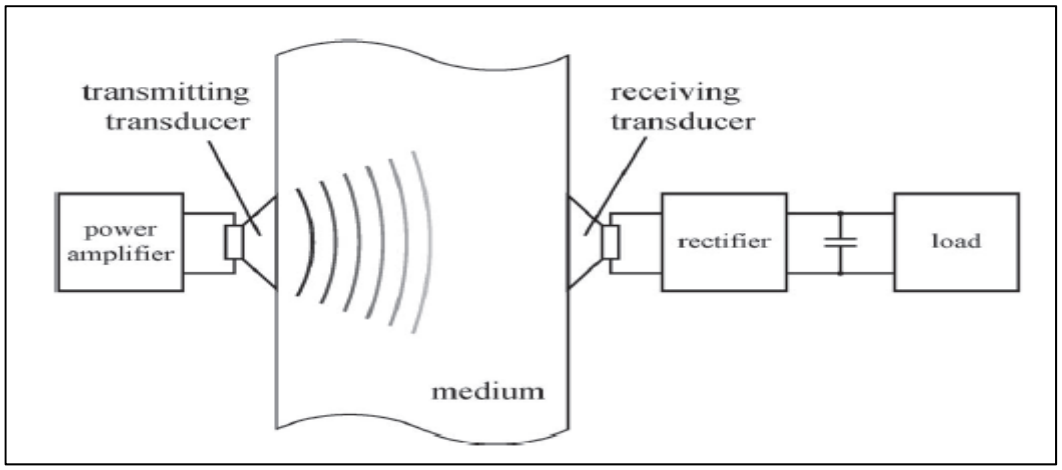

Figure 1.2: An acoustic energy transfer system. [3]

1.5 Structure of Report.

This report consists of five chapters that will explain details about this project. The first chapter is all about the introduction of this project that includes project background, problem statement, objectives, and scopes. It is then adopted by Chapter 2 which provided a literature review on the Wireless Power Transfer (WPT) and focussing on the Acoustic Power Transfer (APT) design. Next, Chapter 3 is the methodology that covered the experimental setup, operations and descriptions method hardware and software part and flow charts of the designing the APT. In chapter 4, it is about the result and discussion from step by step taken throughout methodology of designing the APT system. Lastly, overall on the designing the APT system and future work recommendation has been conclude in chapter 5

CHAPTER II

LITERATURE REVIEW

In this part, the relevant existing work done by researcher will be studied and discussed. Furthermore, the related theoretical part will be explained in detail. This will aid to elevate the knowledge and information about this project and also provide for the completion of the project. The previous works made by researchers is among the aspects for designing this project.

2.0 Background Study of Wireless Power Transfer (WPT)

Nowadays, the wireless power transfer (WPT) system are widely developed and there are many investigated researches done for this system. The purpose of WPT is to supply mobile devices with electrical energy due to elimination and limitation of cables, connectors and/or slips-rings increase reliability and maintenance-free operation of such a critical system s as in biomedical, aerospace, multisensory and robotic application [1]. The most popular use technique in WPT for power transfers are inductive power transfer (IPT), capacitive based power transfer (CPT) and lastly acoustics based power transfer (APT). These techniques are divided according to the medium used for power transfer. There are some other techniques beside the IPT, CPT and APT. There ARE light-based power transfer, optical coupling, and far-field electromagnetic (EM) coupling [2],[3].

2.1 Acoustic Power Transfer (APT)

The acoustic power transfer technique uses sound waves to propagate power without relying on the electrical contact. The basic structure of an APT system is shown in Figure 2.1. A transmitting transducer converts electrical energy into a pressure wave that propagates through a medium. A receiving transducer is positioned at a point along the path of the sound wave for the inverse process of converting the motion caused by the sound wave into electrical energy. A rectifier and a capacitor provide a usable steady dc voltage that drives a load. The medium can be anything ranging from air to human tissue or a solid wall; in principle, any material that will propagate a pressure wave will do [2],[3].

The APT system has it owns features and advantages compared to the IPT and the CPT. First, any given dimensions of the transmitter and receiver, the frequency used in the APT system can be a factor indicating the propagation speed of EM and acoustic waves in air, respectively smaller than that of IPT for the same directionality. Consequently, the losses in the power electronic converter can be lower [2]. Secondly, the APT system can be used where the EM fileds are not allowed [2],[3]. Thirdly, APT system dimension when high directionally is required. Fourtly, the APT system have smaller system dimensentions when high directionally is required. Lastly, the efficiency of the APT system is less than IPT ones. However, when the distance between the transmitter and receiver is much larger than their radii, the efficiency of the APT system can be much more higher[1~3].

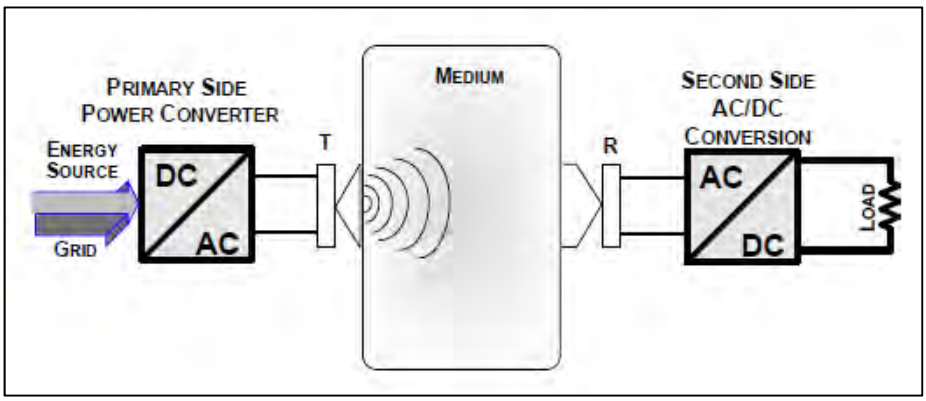

Figure 2.1: The basic principle of APT system [1]

Acoustic energy in its purest form is used in various applications, such as ultrasonic cleaning, medical ultrasonography, nondestructive testing, distance measurement. Example like sonar, therapeutic ultrasound, and ultrasonic welding. These applications are different from APT system in that they directly use the acoustic energy to achieve a specific goal, without converting it back to electrical energy[3].

The APT system are somehow related to the piezoelectric energy harvesting and piezoelectric transformers. Energy harvesters make use of available (vibrational) energy to generate electricity and could be considered to be a nondriven APT system. Piezoelectric transformers convert electric energy into vibrations, with the inverse process taking place at the secondary side, which is the essence of APT. However, it lacks the spatial separation of the transmitter and receiver that is desired for a WPT system [2],[3], [11-12].

2.2 Inductive Power Transfer (IPT)

The inductive power transfer technique uses magnetic fields to propagate power without relying on the electrical contact. The basic structure of an IPT system is shown in Figure 2.2. It consists of primary side DC/AC resonant converter, which converts DC into high frequency AC energy. Next the AC energy via transformer with inductive coupling factor *k* is transferred to the secondary side receiver. The secondary side is not connected electrically with primary and, therefore, can be movable (linearly or/and rotating), giving flexibility, mobility, and safety for supplied loads. In the secondary side, the high-frequency AC energy is converted safely by AC/DC converter to meet the requirements specified by the load parameters. In most cases, a diode rectifier with capacitive filter is used as AC/DC converter. However, in some applications an active rectifier or inverter (for stabilized DC or AC loads) is required [1],[2].