WIRELESS ENERGY TRANSFER (WI-TRICITY)

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DEDICATION

I dedicate my dissertation work to my family and many friends. A special feeling of gratitude to my loving parents, Abas Ahmad and Sadiah Dandu whose words of encouragement and push for tenacity ring in my ears. My wife Nurulhuda Yahya, and my wonderful daughter Puteri Akalili Sorfina who have never left my side, always supporting me physically and emotionally, both of you have been my best cheerleaders. I also dedicate this dissertation to my many friends and who have supported me throughout the process, I will always appreciate all they have done. I would also like to give special thanks to all my classmate for being there for me throughout the entire degree program while studying in Universiti Teknikal Malaysia Melaka.

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.

ABSTRACT

Today in a normal house often can find tons of electronic gadgets, appliances and many other electric equipment and all these is to ease and to suit today's modern lifestyle. All of these have one common thing; the appliances need cables for power supply. Cables are very tedious to manage and install, it is time for the wireless technology to be taken into the next level. While coil has been used to transfer data such as an identification card, the coil can be manipulated to transfer energy with sufficient efficiency to transfer power. The ingenious idea behind this technology is that coil can emits electromagnetic waves that can be transform back into electricity. It is wireless electricity, hence Wi-Tricity. The Wi-Tricity basic concept is relatively simple, but it does take some precise calculation to make it work. This project main purpose is to explore and exploit the wonders or wireless technology with limitless applications and marketability. This project will analyzed the wireless transmission mechanism based on the coupling model of two inductor, and studied the relationship among efficiency, frequency, distance and coil sizes. A system that can transfer current with certain efficiency is expected to be made.

ABSTRAK

Hari ini, disemua rumah kebiasaannya terdapat banyak alat elektronik, perkakasan dan banyak peralatan elektrik yang lain dan semua ini adalah untuk memudahkan serta sesuai dengan gaya hidup moden zaman kini. Kesemua benda ini mempunyai satu sifat yg sama; iaitu peralatan memerlukan kabel untuk bekalan kuasa. Kabel adalah sangat susah untuk dipasang dan diuruskan, Kini tiba masanya bagi teknologi tanpa wayar untuk dipraktiskan ke peringkat seterusnya. Selain digunakan untuk memindahkan data seperti kad pengenalan, gegelung juga boleh dimanipulasi untuk memindahkan tenaga dengan kecekapan tinggi yang mencukupi untuk menghidupkan alatan elektrik dan elektronik. Idea bijak di sebalik teknologi ini adalah bahawa gegelung boleh mengeluarkan gelombang elektromagnet yang boleh diubah semula ke dalam bentuk tenaga elektrik. Ianya dipanggil elektrik tanpa wayar, iaitu Wi-Tricity. Konsep asas Wi-Tricity adalah agak mudah, tetapi ia memerlukan beberapa pengiraan yang tepat untuk membuat ia berfungsi. Tujuan utama projek ini adalah untuk meneroka dan mengeksploitasi keajaiban teknologi tanpa wayar dengan aplikasi tanpa had dan boleh dipasarkan. Projek ini akan menganalisisa mekanisme penghantaran tanpa wayar berasaskan model gandingan dua induktor, dan mengkaji hubungan antara kecekapan, kekerapan, jarak dan gegelung saiz. Satu sistem yang boleh memindahkan tenaga tanpa wayar dengan kecekapan tertentu dijangka akan direka.

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CHAPTER I

INTRODUCTION

1.1 Background

Electricity is a necessity of today modern life. It is difficult to live or passing a day without electricity. Today, Wi-Tricity is also referred as wireless electricity or wireless power transfer has been attracting a great deal of attention. Wi-Tricity will enable advances in the use of electronic devices such as mobile phones, portable computers and etc.

Wi-Tricity is the short form of wireless electricity and it is the transmission of electrical energy from a power source to an electrical load without interconnecting wires. It is used to power on the electrical devices without the exits of wire. Besides that, because of the Wi-Tricity, some of the devices will not require the battery to operate. Although functional, wireless power transfer through induction is constrained to very small distances; the transfer efficiencies get increasingly worse as the distance between transmitter and receiver increases.

There is a demand for wireless energy transfer system. Wireless data transfer via the Ethernet protocol or mostly known as WIFI was developed around 1988 by NCR Corporation and widely commercialized in 1999.Analysts predict that 100 million people will be using Wi-Fi by 2006. Homes, offices, colleges and schools around the world have installed Wi-Fi equipment to blanket their premises with wireless access to the internet. Wi-Fi access is available in a growing number of coffee shops, airports and hotels too. [1] It is not impossible to think that a developed wireless energy transfer technology would have much the same potential in home and business applications as wireless data transfer

experienced. There are many applications, such as cell phones, laptop personal computers, and home theatre equipment, in which wireless energy transfer would be desirable. This study documented the design of a wireless energy transfer system as a basic to more understanding about this system.

In this research, we proposed Wi-Tricity based on electromagnetic resonant coupling. Wi-Tricity is define as the efficient transmission of electric energy from one point to another without the use of wire or any other substance**.** This project will be design bases on the principle of electromagnetism resonant coupling system. When AC power has been supplied through a coil, magnetic field will be generated around the coil. At the moment, if another coil is put aside it, induced current will be produced and caused the magnetic field will also appear around the other coil, which is the reason that the wireless energy transfer is set up between those two coils. Energy will be transfer when both coils will have same resonant frequency

Many of the contactless feed systems are based on the electromagnetic induction's principle. Small distance wireless energy transfer is demonstrated through used of induction. Knowledge of electric circuit logic and electromagnetic theory is important to realize the practical design. The concept of Wireless electricity began with the experiments of Heinrich Hertz and Nikola Tesla at around the 1890s and it still under the research until today. It has been attempted many times throughout the last century.

The advantage of inductive wireless power transfer is that it is a low cost and highly efficient method of transferring power. The design of an induction link is fairly straight forward and surprisingly efficient at small distances.

This thesis provides a literature review of the history of Wi-Tricity throughout the last century. All of the methods that have been used to achieve Wi-Tricity will be reviewed along with the advantages and disadvantages of each method. This thesis will conclude with a small discussion on issues with Wi-Tricity. In order to detailed investigate the principle of the electrical energy transmission; building the model of this scheme is important for the research on transferred power, efficiency, optimizing the structure and parameters, and determining the controlling method.

1.2 History of Wi-Tricity

Magnetic fields and inductive coupling have been studied since the discovery of transformer by Hans Oersted and Michael Faraday. In 1886, Westinghouse Company developed first commercial AC transformer. A complete mathematical understanding of the coupled circuits used to make the transmitter and receiver was first published by Frederick Terman in 1935.

Idea of using microwave power transmission was put forward by William C. Brown in 1961. In 1973, world first passive RFID system demonstrated at Los-Alamos National Lab.

In 1988, a power electronics group led by Prof. John Boys at The University of Auckland in New Zealand, developed an inverter using novel engineering materials and power electronics and concludes that inductive power transmission should be achievable. A first prototype for a contact-less power supply is built.

In 2007, a physics research group, led by Prof. Marin Soljačić, at MIT confirm the earlier (1980's) work of Prof. Boys by wireless powering of a 60W light bulb with 40% efficiency at a 2 meters distance using two 60 cm-diameter coils.

In 2010, Haier Group debuts the world's first completely wireless LCD television at CES 2010 based on Prof. Marin Soljačić's research on wireless energy transfer and Wireless Home Digital Interface (WHDI).

1.3 Problem Statement

In general, the battery technology is the major approach to supply the power of these systems. The advantage of the approach is technically simple. However, unacceptable problems such as the hidden danger of battery and the low capacity that cannot satisfy the high power consumption requirement of system, limit its development.

Besides that, standard wired charging device also experiences wasted power in that a charger left plugged into an electrical outlet while the device is not attached wastes as much as 93% of the power it pulls over its entire lifetime. Also, the manufacturing and

disposal processes of zinc-carbon, alkaline, and lithium-ion batteries entail significant carbon emissions. If Wi-Tricity technology can replace 2% of battery powered devices in one year, 11,600 metric tons of CO_2 can be saved. Wi-Tricity can improve energy efficiency, reduce mercury waste, and preserve clean air by diminishing a reliance on battery power and the subsequent carbon emissions [1].

Not only that, conventional power transfer provide unacceptable problems such as the tripping hazard. Tripping hazard is difficult to prevent unless we think about them as we work with the things that can create them. The only way to avoid the tripping hazard is to reduce the use of wire or it can be improve by Wi-Tricity product.

Furthermore, another serious unacceptable problem occurred with current wire power transfer system is people might get electrical shock during flood. There are too many incident happen in electric shock victims during flood. Wi-Tricity can prevent this incident happen because no wire is required and it's transfer energy in electromagnetic form. So that, people will not get electrical shock in this kind of energy transfer.

Wireless transfer energy is an intimidating task because few people have ever been able to perform it efficiently at longer distance and then only with a very low amount of power. Even though there are many applications that would benefit from the ability to transfer energy wirelessly such as the charging of laptop personal computers and cell phones, but the theories about the wireless energy transfer are still very little and studies about it are only from physics. This prototype is important to show and demonstrate the concept of the wireless energy transfer to the public hopefully the appropriate technology will be developed from time to time to satisfy these applications.

1.4 Objective

The main objective of this final year project is:

1) To Analyze the Wi-Tricity power based system and output.
2) To investigate the energy transfer efficiency.
3) To improve the efficiency and implement of Wi-Tricity system control.

Definition

This report proposes a wireless energy transfer prototype that is targeted at delivering enough power to light up a 3V of LED and charging a Hand phone of 5V. It was used as the target for the amount of energy needed at the receiving coil. This project is a starter idea for the next consumer products after this. At the beginning of this project, we only focus on the production of prototype models to help people to more understand about the concept of wireless energy transfer. The objective of this study is first to investigate the principle of the electrical energy transmission, efficiency optimizing the structure and parameters, and determining the controlling method. The second objective is to build a prototype model that can delivered electrical to light up a 3V LED receiver wirelessly.

1.5 Scope of work

When we discuss about transferring energy without wire, the method of transferring must be choose. In this project, we choose to transfer energy wirelessly based on magnetic couple resonator. The reason we choose this method on transferring energy is because it non-radioactive and have the big potential to be apply to the electronic consumer.

The scope that covered in this project is only on hardware. For the aspects of hardware it consists of a transmitter, a handmade air core inductor which acts as an electromagnetic resonator and a receiver, another copper coil of similar dimensions to which the 3V LED and 5V DC charging unit to be powered is attached. We use 240V Lab Power Supply to step down voltage from 240V to 12V. We will supply 12V DC and then change it to AC by using filter to make the coil to oscillate and produce magnetic field. It also will connect to function generator to supply high frequency to transmitter. We will analyze the parameter based on frequency and distance. Means, from the prototype model we will show how the distance will affect the transferring of electrical energy transmitter to receiver.

1.6 Methodology

In order to investigate and analyze the Wi-Tricity power based and to improve efficiency and implement of Wi-Tricity system control, an idea of developing and implementing Wi-Tricity system control is pick through analyzing the situation. Two approaches were used in collecting primary data to gain information, ideas and suggestions in further developing this system. Firstly, in the theoretical approach, researching the selected topic is selected to seek the information towards this system. Besides that, reading journal, books, magazines, as well as articles from the library will also help me in completing this study. Secondly, the experimental approach to test the hypothesis underlying my study. This experiment was conducted in order to investigate the energy transfer efficiency of Wi-Tricity system. After that, designing the project circuit is important to make sure the efficiency of the system. Last but not least, make the troubleshooting to detect the problems that arise in order to complete the research.

1.7 Thesis Outline

The remainder of this thesis is organized as follows:

Chapter 2, *Theoretical Review*, the concept of the Wi-Tricity system control is studied to understand the concept of wireless energy transfer in order to design the appropriate circuit.

Chapter 3, *Literature Review*, history of wireless energy transfer is analyzed and the propose project is compared with the current technology. Besides that, the others method of transferring energy is also analyzed.

Chapter 4, *Research Methodology*, the proper procedure in designing and manufacturing of the system is discussed.

Chapter 5, *Result and Discussion,* the result of the experiment is presented. The experimental result is discussed and analyzed for future improvement.

Chapter 6, *Conclusions and Recommendations,* conclusions from the results is drawn and a future area for research is recommended.

1.8 Summaries of Chapters

Introduction was included to briefly explain some important parts of whole project, objective of project, problem statement of project, scope of work and the methodology of the project.

Theoretical review shows the detail concept of the wireless energy transfer and the working concept of the whole project. This chapter includes electromagnet induction, resonance frequency of the system, and quality factor of the system and detail concept of inductor.

Literature review shows the details in different designs of Wi-Tricity system control circuit construction and different functions which were used to be discussed, compared to the current Wi-Tricity system.

In methodology, a brief flow of project from discussing the project with supervisor, until the end of presentation and technical report was described. Besides that, the flow in manufacturing the transmitter and receiving coil is discussed in detail.

Expected results and discussion shows the expected results of this project, the range of the wireless energy transmission, the relationship between the source frequency and the resonance frequency.

Finally, results and discussion, related to objective; benefits on Designing and Implementation of Wi-Tricity System Control and the whole project were concluded in conclusion.

CHAPTER II

THEORETICAL REVIEW

2.1 True Concept of Electromagnetic Inductive Coupling

This chapter will discuss the detail concept of how the energy can be transferred wirelessly and the theory or the equation that involved in the wireless energy transfer model.

2.2 Concept of Electromagnetism

The term electromagnetism is defined as the production of a magnetic field by current flowing in a conductor. Understand electromagnetism in greater detail is needed to understand how it can be used to do work.

Magnetism is a basic force of nature that causes certain types of material to attract or repel each other. Permanent magnet is an example of objects having stable magnetic fields. Oscillating magnetic fields diverge with time, and can be supplied by alternating current flowing on a wire.

Electromagnetism is the strength that causes the interaction between charged particles. The area in which this happens is called electromagnetic fields. The moving electric charges in a conductor create magnetic fields where the moving magnet in a conductor creates magnetic fields. This effect is called electromagnetic induction and is the starting point of operation for wireless energy transfer or Wi-Tricity System.

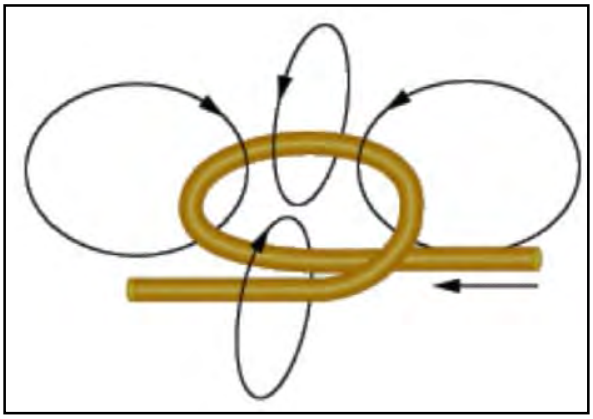

Figure 2.2.1 Magnetic field around wire

The form of the magnetic field around the wire is shown in Figure 2.1.1. The magnetic field in circular form is developed around the wire. The field generated is perpendicular to the wire and that the field's direction depends on which direction the current is flowing in the wire. The easy way to increase magnetic field is to coil the wire because the magnetic field around a wire is circular and perpendicular to the wire.

2.3 Electromagnetic Induction

Electromagnetic induction is the creation of an electrical voltage or potential difference across a conductor within a changing magnetic field.

When a conductor cuts across a magnetic field, current flows in the conductor. It flows one way when the conductor cuts the field in one direction, then reverses as it cuts the field in the opposite direction.

The current is called alternating because it is flows in one way, and then the other. The term alternating current is often shortened to AC. That's the sort of electrical energy that comes through power outlets. It's also produced by an alternator, as the name indicates.

Moving a wire inside a magnetic field produces a current flow. Similarly, moving a magnet inside a stationary coil of wire produces the same effect. If a magnet is rotating in an iron yoke, and a coil of wire is wound around the stem of the yoke to form a complete circuit with the ammeter, this will indicate if current flows.

2.4 Resonance Frequency

Resonance is a trend that one physical system in its natural frequency tends to absorb more energy from the environment. In other words, it is a phenomenon that one object vibrates which cause the other one with the same frequency vibrates. Resonances can transfer energy.

Electromagnetic resonance exists widely in electromagnetic system. The electromagnetic field itself is an energy field which can provide energy to used electric apparatus. Considering its danger to people and other organisms in electric field, the magnetic field is safe and more suitable to be used as the energy-transfer medium in magnetic resonances energy transfer.

The radiating electromagnetic wave itself contains energy, no matter whether there is a receiver or not, the energy of electromagnetic wave is continuously consumed. If we can make a non-radiative magnetic field with a certain resonance frequency, when the resonator, such as the LC oscillating circuit, with the same resonance frequency in it, the electromagnetic resonance is generating, energy in the inductance coil continues gathering, the voltage is increasing and the receiving energy will be produce. [5]

2.5 Resonance with Capacitor and Inductor

When an inductor or capacitor is placed in series or parallel they will have a resonant frequency which is determined by the design equation below. Resonance occurs when the reactance of an inductor balances the reactance of a capacitor at some given frequency. In such a resonant circuit where it is in series resonance, the current will be maximum and offering minimum impedance. In parallel resonant circuits the opposite is true. LC resonant circuits are useful as notch filters or band pass filters. They are also found in oscillator circuits. It occurs at a particular frequency for particular values of inductance and capacitance so that it can be unsafe to the operation of communications circuits by causing unwanted persistent and transient oscillations that may cause noise, signal distortion, and damage to circuit elements.

Since the inductive reactance and the capacitive reactance are of equal magnitude,

$$\omega L = 1/(\omega C),$$

As

$$\omega = \frac{1}{\sqrt{LC}} \tag{2.1}$$

where $\omega = 2\pi f$

$$f = \frac{1}{2\pi\sqrt{LC}} \tag{2.2}$$

where $\omega = 2\pi f$,

in which *f* is the resonance frequency in Hertz, L is the inductance in

Henries, and *C* is the capacitance in Farads when standard SI units are used.

2.6 Resonant Energy Transfer

Resonant energy transfer or resonant inductive coupling is the short distance wireless transmission of energy between two coils that are highly resonant at the same frequency. The equipment to do this is sometimes called a resonant transformer. This type has a high Q and always used an air cored coil to avoid iron losses is a lot of transformers. The coils may be present in a single piece of equipment or in split pieces of equipment. Resonant transfer works by construct a coil ring with an oscillating current. It occurs when AC voltage have been supplied through coil which generates an oscillating magnetic field. Because the coil is greatly resonant, any energy placed in the coil lost away relatively slowly over very a lot of cycles but if a second coil is brought near to it, the coil can pick up most of the energy before it is lost, even if it is some distance far away. [4]

2.7 Resonant Coupling

Non resonant coupled inductors, such as transformers, work on the principle of a primary coil generating a magnetic field and a secondary coil attach as much as possible of that field so that the energy passing though the secondary is as similar as possible to that of the primary. This condition that the field be covered by the secondary results in very short range and usually requires a magnetic core. Over larger distances the non-resonant induction method is highly inefficient and wastes the lots of the energy in resistive losses of the primary coil.

Using resonance can help efficiency significantly. If resonant coupling is used, each coil is capacitive loaded so as to form a tuned LC circuit. If the primary and secondary coils are resonant at a general frequency, it turns out that significant energy may be transmitted between the coils over a range of a few times the coil diameters at reasonable efficiency.

2.8 Basic of Inductor

An inductor is a passive electrical device working in electrical circuits for its property of inductance. An inductor can seize in a many forms. Inductance is an outcome which results from the magnetic field that forms around a current carrying conductor. Current flowing throughout the inductor produces a magnetic field that is has a related electromotive field which opposes the applied voltage. This counter electromotive force is generated which opposes the change in voltage applied to the inductor and current in the inductor resists the change but does increase. This is identified as inductive reactance. It is reverse in phase to capacitive reactance.

Inductance can be improved by looping the conductor into a coil which creates a bigger magnetic field. The unit of inductance is Henries (H).

2.9 Quality Factor of Inductor

The quality factor is a value of the quality of a resonant system. Resonant systems react to frequency close to their natural frequency stronger than they respond to other

frequencies. The quality factor indicates the quantity of resistance to resonance in a system. Systems with a high quality factor resonate with better amplitude at the resonant frequency than systems with a low quality factor. In a circuit, inductors have a series resistance produced by the copper or other electrical conductive metal wire forming the coils. The series resistance changes the electrical current flowing through the coils into heat, hence causing a loss of inductive quality. This is where the quality factor is born. The quality factor is a relative amount of the inductance to the resistance.

$$Q = \frac{\omega L}{R} \tag{2.3}$$

Where ω is resonance frequency, L is inductance and R is internal electrical resistance of coil.

Higher quality factor indicates a lower rate of energy loss relative to the stored energy of the oscillator. Oscillators with higher quality factors have low damping so that they can ring longer. Sinusoidal driven resonators having higher quality factors resonate with greater amplitudes but have a smaller range of frequencies around that frequency for them to resonate. High quality oscillators oscillate with a smaller range of frequencies and are stable. [5]

2.10 Construction of Inductor

An inductor is generally constructed as a coil of conducting material, usually copper wire, wrapped around a core either of air or of ferromagnetic material. Core materials with a higher permeability than air raise the magnetic field. Inductors come in many shapes. Most are constructed as enamel coated wire wrapped around a ferrite coil with wire exposed on the outside, while some include the wire completely in ferrite and are referred to as shielded. Some inductors have a flexible core, which enables changing of the inductance.