WIRELESS POWER TRANSFER CHARACTERISTICS OBSERVATION USING INDUCTIVE COUPLING METHOD

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Especially to my beloved family ANAB YASIN
ABDI. AHMED HERSI MUSE, MOHAMED HERSI MUSE,
HODO HERSI MUSE

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ABSTRACT

The purpose of this project is designing and modelling of a system for WPT using inductive coupling to eliminate the use of wires. In this project the problem of using the wires which will reduce the efficiency of the system will be eliminated. There are many ways to overcome the energy that will be dissipated in the wires of the wired systems, and here in this project will model one of those techniques which is inductive coupling. This method will help to transfer the power wirelessly and the use of the wires will be eliminated, but with less distances. This project will give information that the power is transferred wirelessly and the distance effect for the output power of the WPT. Still some of the low power devices need a developed procedure for safe and accurate wireless power transfer. So this project will highlight some aspects for wireless power transfer. By using math lab Simulink maximum efficiency was achieved while the coupling coefficient K was 1 which is 97.33% in both theoretical and simulation results.

ABSTRAK

Tujuan projek ini adalah merancang dan memodelkan sistem untuk WPT menggunakan gandingan induktif untuk menghilangkan penggunaan wayar. Dalam projek ini masalah penggunaan wayar yang akan mengurangkan kecekapan sistem akan dihapuskan. Terdapat banyak cara untuk mengatasi tenaga yang akan dikeluarkan dalam kabel sistem kabel, dan di sini dalam projek ini akan memodelkan salah satu teknik yang merupakan gandingan induktif. Kaedah ini akan membantu mengalihkan kuasa secara wayarles dan penggunaan wayar akan dihapuskan, tetapi dengan jarak yang lebih sedikit. Projek ini akan memberi maklumat bahawa kuasa dipindahkan secara wayarles dan kesan jarak untuk kuasa output WPT. Masih beberapa peranti kuasa rendah memerlukan prosedur yang dikembangkan untuk pemindahan kuasa tanpa wayar yang selamat dan tepat. Jadi projek ini akan mengetengahkan beberapa aspek untuk pemindahan kuasa tanpa wayar. Dengan menggunakan makmal matematik Simulink kecekapan maksimum dicapai manakala pekali gandingan K adalah 1 iaitu 97.33% pada hasil teori dan simulasi.

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WPT	Wireless Power Transfer
Q	Quality factor
K	coupling coefficient
AC	Alternating current
DC	Direct current
PTE	Power transfer efficiency

CHAPTER 1

INTRODUCTION

1.1 Introduction

Electricity is essential to modern life and is transferred from power plants to electric devices through wires. However, because many people wish to use electric devices wirelessly, batteries are widely used for mobile devices. In this regard, if the required power for such devices could be transferred continuously without the use of any wires, modern life would be much more convenient [1]. Accordingly, a wealth of studies on wireless power transfer (WPT) has been reported in the literature. Nikola Tesla introduced a kind of WPT system using millions of volts of electricity and managed to create several that can be classified into three main categories: radiative, non-radiative capacitive coupling, and non-radiative magnetic coupling [2]. Radiative and non-radiative capacitive coupling are not convenient to use when it comes to transfer relatively large power [3].

WPT is basically the transmission of electrical power from a source to an electrical load wirelessly. Thus the fundamental technologies are electricity, magnetism and electromagnetism. Material attracts or repels each other by a natural force called magnetism. Oscillating magnetic fields exist between these materials, which produce alternating current (AC) [4].The strength, direction and extent of magnetic fields are envisaged by sketching of magnetic field lines.

Magnetic field in Figure 1mrepresents by B, current is represented by I and the arrow shows the direction of current to which conventional current is flowing. The magnetic flux is shown by different lines due to different directions.

The magnetic field is strong when the lines of flux are uniform and B is low where the magnetic flux lines are not uniform [5].

Electro-Magnetism is a combined term used for electric and magnetic fields simultaneously. The OMF generates an electric field and magnetic field. A magnetic field is created when a current flows through a conductor. By using the Fleming left hand rule, direction B, I and F can be found.

1.2 Problem Statement

The main drawback of using the wired power transfer is the losses due to the energy dissipated in the conductor and other equipment used. The main reason for power loss during transmission and distribution is the resistance of wires used for the grid and as technology grows in the world, nowadays one of the efforts is trying to transmit power wirelessly. The wireless power transfer system using magnetic resonant coupling mode is significant to be implemented towards mobile phone chargers as there is no conventional power cable that needs to be connected during the charging process.

To achieve an efficient wireless power transfer system, the configuration of transmitter and receiver design becomes the main focus in the wireless power transfer system. In this study there are some solutions to transfer power effectively from transmitter to receiver using inductive coupling, so that much research is done, and still going to solve the challenges and limitations faced by this topic. So this project will analyse how the coupling coefficient and efficiency of wireless power are related, by considering different parameters.

1.3 Objective

i. To design a wireless power transfer system using an inductive coupling method characteristic observation.
ii. To evaluate performance of the proposed wireless power transfer system in terms of power transfer efficiency

1.4 Scope

The scope of this project will follow the below steps:

i. First the theoretical calculations must be done to ensure how coupling coefficient and combined quality factor are affected the efficiency.
ii. The simulation for the transceiver circuit using math lab and transmitting power effectively.
iii. The project application is restricted to the low-power application, which is the mobile phone charger. The maximum output is power up to 15 W with maximum transfer distance is from 10mm to 100mm.
iv. Determining the optimal efficiency of the system by varying the distance and coupling coefficient.

1.5 Project outline

The outline of this project will be organized as following:

i. Ch. 2 starts with a presentation of the literature review and basic theories of resistance, inductance, induction, resonance as well as different topologies of WPT systems.
ii. Ch. 3 will design the different parts of the system like transmitter circuit, receiver circuit, power conversion blocks, e.g.: oscillator circuit using MATLAB software.
iii. In Ch.4 will present the theoretical calculations and simulation results and discussion of the designed components such as transceiver circuit oscillator circuit using mat lab.
iv. The conclusion and recommendation will be covered in chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Wireless power transfer (WPT), in its general term, has been around us for decades in applications such as telemetry, satellite communications, and radio frequency identification (RFID) tags [2]. Most of these applications transfer low amounts of power, in the range of microwatts to milliwatts, for data transfer. For higher-power applications, from few watts to several kilowatts, over moderate distances, the WPT has recently been the focus of industrial developments. The most common method of high power WPT is through inductive coupling that was invented by Nikola Tesla more than a century ago. The recent developments in the semiconductor industry for high frequency and high-power applications have paved the path for high-power inductive WPT improvements. Inductive WPT offers several benefits over the wired connection and is applied in numerous applications such as wearable electronics, health care, and automotive industry [6]

This chapter starts by reviewing various methods of WPT, followed by the design and analysis of inductive WPT. The overall inductive WPT is studied step by step and component by component; therefore, it is recommended to refer to the references for detailed analysis and information.

2.2 Concept of the wireless power transfer

Power can be transferred over short distances (near-field transfer) by alternating magnetic fields and inductive coupling between coils, or by alternating electric fields and capacitive coupling between metal electrodes. Inductive coupling is the most common method of WPT and is used in charging devices such as smartphones, electric shavers, visual prostheses, and implantable medical devices [7]. Figure 2.1 shows the block diagram of wireless power transfer which shows how power can be transferred without physical contact.

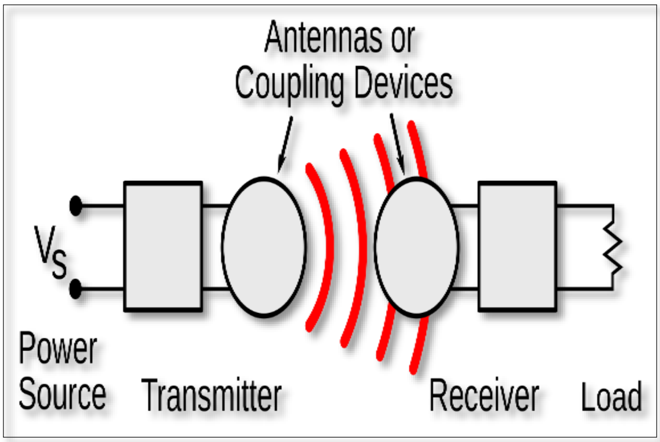

Figure 2.1- block diagram of wireless power transfer.

The concept of inductive coupling and magnetic field comes from the following principles:

2.2.1 Faraday's Law of induction

Faraday's Law of Induction describes how an electric current produces a magnetic field and, conversely, how a changing magnetic field generates an electric current in a conductor, and states that changing magnetic field is directly proportional to the change of that magnetic field [1], as shown in Figure 2.2.

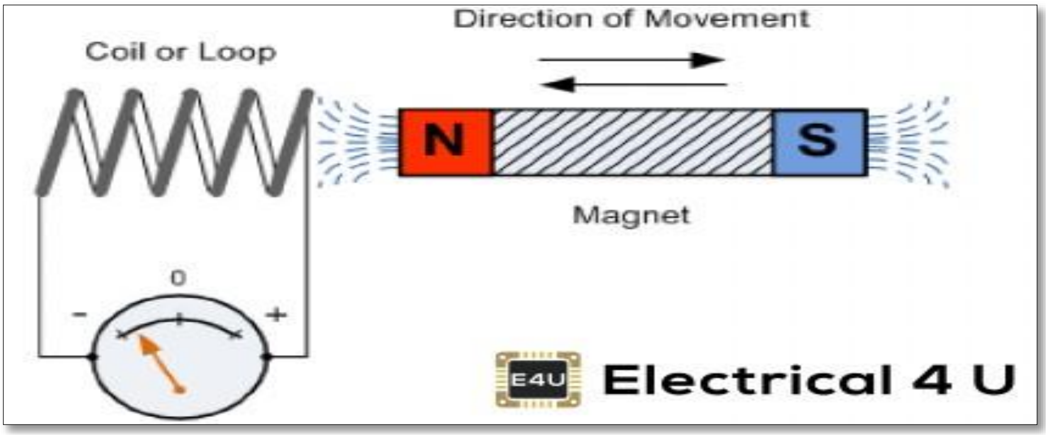

Figure 2.2: Faraday's Law of Induction

2.2.2 Ampere's law

Ampere's law states that for any closed loop path, the sum of the length elements times the magnetic field in the direction of the length element is equal to the permeability times the electric current enclosed in the loop [1].

2.2.3 Lenz's law

The induced electromotive force with different polarities induces a current whose magnetic field opposes the change in magnetic flux through the loop in order to ensure that original flux is maintained through the loop when current flows in it [8].

$$Emf = -N\left(\frac{\Delta\phi}{\Delta t}\right) \tag{2.1}$$

2.3 Types of wireless power transfer configuration

The types of wireless power transfer can be classified based on the distance of transmission, maximum power, and method used to achieve power transmission. Figure 2.3 shows several techniques used to achieve wireless power transfer configuration and other classifications [5].

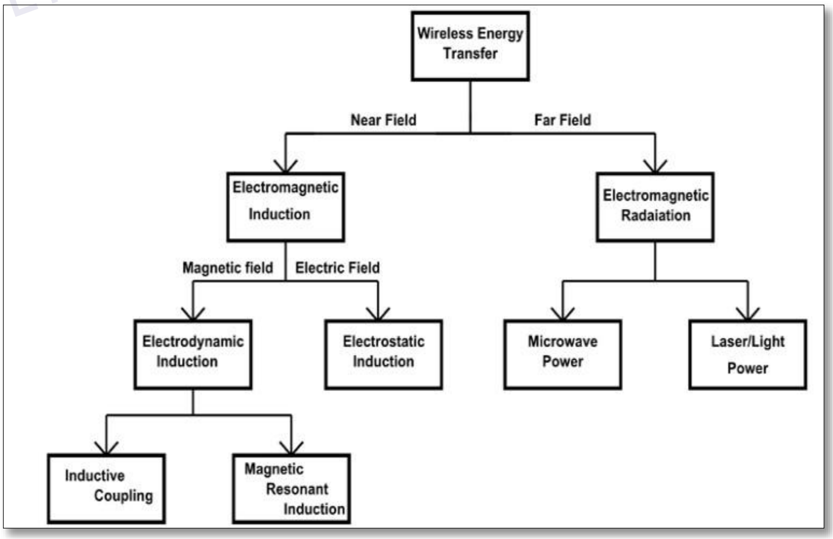

Figure 2.3: block diagram of wireless power transfer.

2.4 Overview of an Inductive Power Transfer System

The wireless power transfer can be carried out by means of acoustic techniques, capacitive, microwave, light/laser, inductive power transfer and wireless power transfer strong coupled magnetically resonance [9]. In the above technologies it can be concluded that acoustic techniques have a very short distance. Similarly, capacitive techniques have low efficiency as well as short distance up to 1mm and Microwave light techniques have reduced efficiency up to 25%. The latest usable inductive contactless energy transfer and wireless power transfer strong coupled magnetically resonance have importance to focus on because of high efficiency [9]. By looking at the low maintenance cost, higher efficiency and maximum output power (MW), the inductive contactless energy transfer is a universal solution for wireless energy transfer.

Inductive power transfer system mainly consists of two coils (inductor). These coils are linked with each other through mutual inductance as shown in Figure 2.4. Mutual inductance depends upon distance between them and is related inversely with distance. Two coils are basically primary and secondary coils.

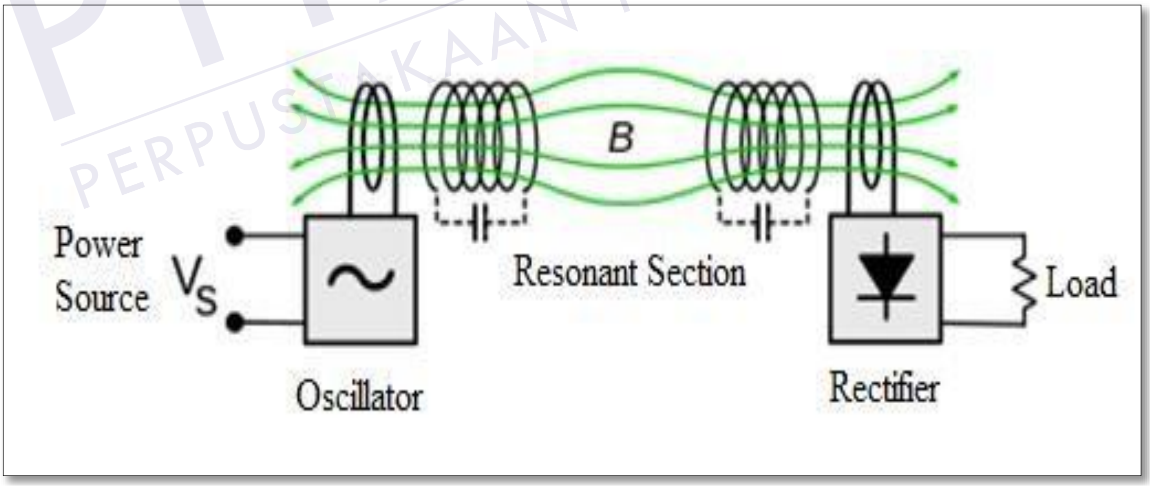

Figure 2.4 Mutual Induction between primary and secondary coils.

When AC current flows through the primary section a magnetic field is produced. According to Faraday's law of induction a time varying magnetic field is produced in secondary due to which current flow is starting in it. Secondary voltage is produced in the secondary coil because of mutual induction. In Figure 2.5, inductive power transfer techniques are implemented between two coupling inductors. These are resonantly coupled to each other through mutual induction. The combined magnetic field between primary and secondary inductors are represented by B. AC power is transmitted wirelessly and then rectified by a bridge rectifier. The rectified output is fed into an electronic device for charging. This system can be extended into a multiple receiver system via impedance matching network or by different transmitting coils [10]. Table 2.1 shows the different techniques of wireless power transfer.

Table 2.1 different technique of wireless power transfer

Techniques	**Advantages**	**Disadvantages**
Inductive coupling	Simple, safe, and high transfer efficiency in short distances.	Short transmission distance needs.
Magmatic resonance coupling	Long transmission distance, no radiation.	Accurate alignment. Difficult to adjust resonant frequency for multiple devices.
Electromagnetic radiation	Very high transmission efficiency over a long distance.	Produces radiation, needs a line of sight.

2.5 Magnetic Induction

When an AC source is connected across a conductor, then AC current starts to flow through the conductor and generates an OMF around the loop. If in proximity, a secondary coil is located closely to the first conducting loop, then the oscillating magnetic field covers the second loop which creates an emf in the secondary coil.

This process is called magnetic induction. Examples of magnetic induction are electric transformers and electric generators. Faraday's law covers the phenomenon of electromagnetic induction, he illustrates that when there is a change of flux lines linking with primary coil, and an emf is induced in the receiver coil due to magnetic induction. Magnitude of voltage induced can be found by multiplying the rate of change of flux with the number of turns [11].

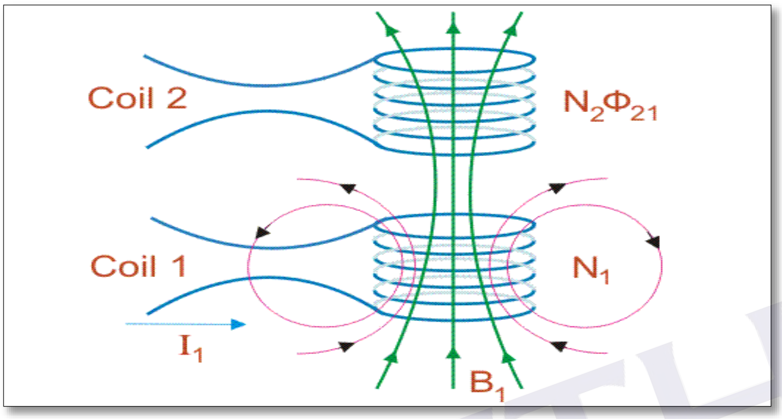

Figure 2.5-Mutual induction between coil 1 and coil 2

In Figure 2.5, the primary turns are represented by N1, secondary turns are represented by N2, and magnetic field in coil 1 is represented by B1. When current flows through coil 1, a magnetic field is produced in it due to which current flows in coil 2 and emf produced in coil it. This is basically the proof of Faraday's law of electromagnetic induction between primary and secondary [11]. Voltage induced in secondary is increased when distance between coils is decreased.

2.5.1 Energy/Power Coupling

This is the ability of one object's magnetic field to generate an electric current into the second object through magnetic induction on close proximity. This phenomenon of transferring power is called power coupling. It is closely related with mutual induction of Faraday's Law of electromagnetic induction. It illustrates that when there is a variation in magnetic flux in primary coil an emf is generated in secondary coil and current starts to flow in that coil [12].

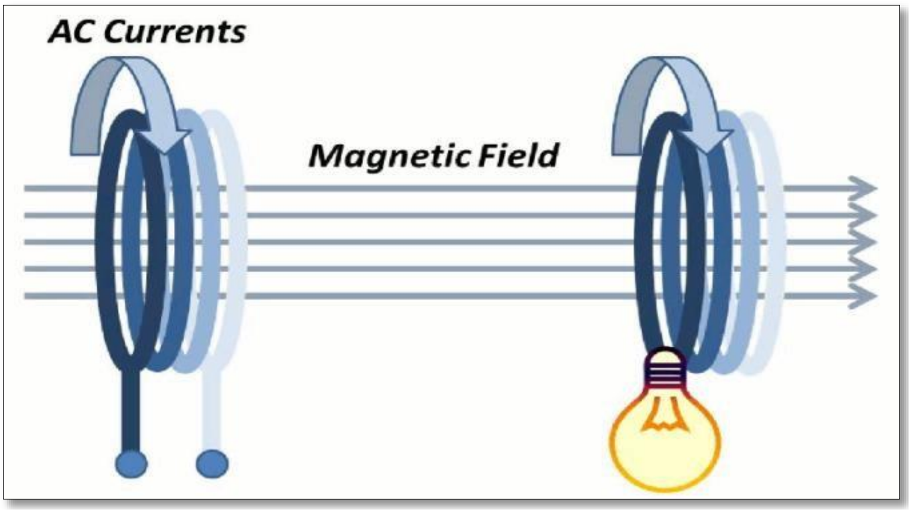

Figure 2.6 Magnetic coupling between transmitter and receiver

In figure 2.6, when AC current is flowing in the primary coil an emf is generated in the secondary coil due to energy/power coupling. The field flux is shown by straight arrow lines. Magnetic field is very strong when lines of flux are straight etc.

2.6 Resonance

Resonance is a phenomenon in which at natural frequency most of energy transfers to an oscillating system efficiently. In this phenomenon the magnetic system retains magnetic moments as well as angular momentum.

2.6.1 Resonant Magnetic Coupling

Through magnetic coupling energy between two objects is exchanged by means of varying magnetic fields. Resonant coupling occurs when the resonance frequency of two systems become equal. The inductive impedance is equal to the capacitive impedance when resonance conditions occur. At this condition the frequency is called resonance frequency.

2.6.2 Resonant coupling

It is also known as magnetic phase synchronous coupling. It is the type in which the secondary side of the coil is loosely coupled and the coupling is increased by resonating the coil. The basic system for resonant inductive coupling includes a primary coil and a resonant inductive circuit on the secondary coil [4] The resonant inductance and capacitance of the secondary side are together called a resonant circuit. When the rate of change of magnetic field of the primary is at the resonant frequency of secondary sides, the phases of the primary and secondary magnetic fields are interlocked. This is done to achieve the maximum output [12].

If high frequency is used the impedance of the system as seen from the power source becomes more and more inductive, and this will cause the power factor to be smaller and smaller. This result in more reactive power to circulate in the system, therefore the inverter will need more VA rating. The power transfer will reduce due to circulating reactive power [8]. To make the power transfer capability enough, and to decrease the inverter's size, a capacitive compensation is required. As a result, the impedance as seen from the source becomes purely resistive.

By taking the advantage of the inductance and the capacitive, resonant coupling will compensate for the leakage inductance [12]. The system compensations can be done in two ways, either by adding capacitors to the circuit or letting the system coils resonate at its own frequency [5]. In choosing the capacitance, choose it so that it cancels out the inductance.

2.7 Applications of wireless power transfer (WPT)

The applications of WPT include the following:

i. Consumer electronics
ii. Transport
iii. Heating and ventilation
iv. Industrial engineering
v. Model engineering [13]

2.8 Advantages and limitations of WPT

Wireless power can be defined as the transmission of electrical energy from a power source to an electrical load without connecting wires and for that reason there are many advantages of WPT. It is reliable, efficient, fast, low maintenance cost, and it can be used for short range or long range. The basic working principle of wireless power transfer is, two objects having similar resonant frequency and in magnetic resonance at powerfully coupled rule tends to exchange the energy, while dissipating relatively little energy to the extraneous off-resonant objects [13].

2.9 Limitations

If the gain of the transmitter and receiver is high it may cause damage to human life since radiation is generated which may cause cancer [13] .Since this project used low application design and the distance is shorter it does not create much radiation.

2.10 Research gap

Basically, this study is focusing on optimization of wireless power transfer systems in order to achieve high power transfer efficiency. Several important parameters are considered in this project such as inductive coupling, distance, high frequency of transfer power, which produce a higher power density for the transfer process. Other than that, application of magnetic resonant coupling method enables a longer distance power transfer due to the concept of resonance in the system. Coupled resonators are basically two objects of the equal resonant frequency that interchange energy efficiently without much leakage. Increasing the coupling coefficient between the transmitter and receiver by optimizing the coil configuration of the system can affect the output power. Some studies deal with varying arrangements of the coil with changing compensation circuits to observe and analyze the PTE of the system. LCC topology is considered in this project. From those parameters stated, a high efficiency of wireless power transfer system is possible to be achieved [14].

2.11 Conclusion

In this chapter, several aspects related to development of IPT techniques for wireless power transfer systems have been explored and investigated. In particular issues related to the designing of IPT systems for low power systems have been assessed to highlight the proposed techniques in the literature. More details regarding the research methodology will be covered in the next chapter.

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