Research Article

Resonant Inductive Coupling for Wireless Power Transmission

Puteri Athira[1], Tze-Zhang Ang[1,*] and Mohamed Salem[1]

[1]Affiliation 1; School of Electrical and Electronic Engineering, Universiti Sains Malaysia (USM), Nibong Tebal, 14300, Penang, Malaysia.
putriathira@student.usm.my, salemm@usm.my
***Correspondence**: angtzezhang@student.usm.my;

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Abstract: Wireless power transmission (WPT) is the method that transferring electrical energy from power source to electrical without any physical contact and it can be used to transfer power to electricity dependent systems or devices. In WPT, electromagnetic energy is produced to transmit the energy from power source (transmitter) to the load (receiver) via resonant inductive coupling. This article focuses on the design of a resonant inductive coupling using parallel-T topology in coupling WTR and combined of single transmitter with multiple receivers. In addition, principle of magnetic wave between the transmitter and receiver with related parameters is utilized to develop in WPT. A parallel-T topology that consists of T-matching network for secondary side is proposed as it is more suitable for weak coupling wireless power transfer applications. Besides that, three circuits are designed to show the resonant inductive coupling for WTP which including the circuit with and without matching network and the circuit of single transmitter with multiple receivers. The simulation of output voltage and output current are observed to relate the effects of frequency on the circuit. The graph of output voltage and power are plotted to show the pattern on effect of the frequencies to the resonant inductive coupling circuit.

Keywords: Wireless Power Transmission (WPT); Resonant Inductive Coupling; Magnetic Field

1. Introduction

Wireless power transmission (WPT) is the transfer of electric energy from a power source to an electric load without a direct physical connection between them where it is usually via an electromagnetic field [1, 2]. In a WPT system, the primary coil and secondary coil are loosely coupled [3]. It can be applied to a wide variety of applications and environments. An example of block diagram for WPT is shown in Figure 1.

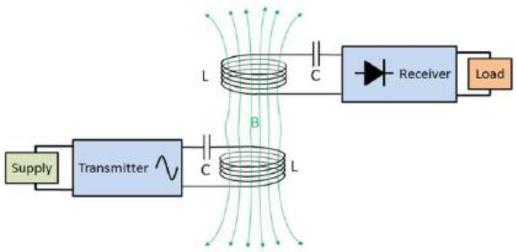

Figure 1. Block diagram of WPT induction coupling method

In the 1890's, a WPT system has been demonstrated by Nikola Tesla who has attempted the first experiment about WPT and also shows a demonstration on Tesla coil which is the resonant transformer that transfers the electrical energy from primary coil to secondary coil with resonant induction [1]. In 20th century, a system for transferring large amounts of power across continental distances in a bid to bypass the electrical-wire grid has been developed by Nikola Tesla [1]. Not only that, this author was able to make a successful in the field of wireless power transfer including illuminating light bulbs with a distance about 30 meters (m) [4].

2. Literature Review

A. Principle of Magnetic Wave

Electromagnetic radiation is a form of energy emitted by moving charged particles in a wave pattern and has an oscillating electric field component and an oscillating magnetic field as it travels through space [5]. These waves oscillate perpendicularly to and in phase with one another. Electromagnetic wave is a self-propagating transverse wave of oscillating electric and magnetic fields which is shown in Figure 2. The direction of the electric field is indicated in blue, the magnetic field in red, and the wave propagates in the positive x-direction. Electric and magnetic field waves are in phase [6].

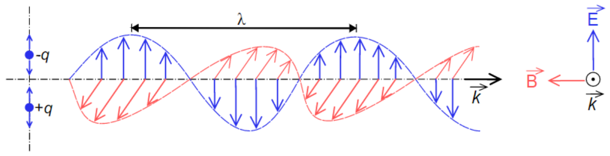

Figure 2. The concept of Electromagnetic Wave

The creation of electromagnetic waves begins with a charged particle and then it exerts forces on other nearby charged particles to form electric field [6]. In addition, when it accelerates as part of an oscillatory motion, the charged particle creates ripples, or oscillations, in its electric field, and also produces a magnetic field [6].

A stationary charge will produce only an electric field in the surrounding space whereas a magnetic field is produced if the charge is moving`. An electric field can be produced also by a changing magnetic field. The mutual interaction of electric and magnetic fields produces an electromagnetic field, which is considered as having its own existence in space apart from the charges or currents (a stream of moving charges) with which it may be related. Under certain circumstances, this electromagnetic field can be described as a wave transporting electromagnetic energy [7].

Wireless charging works by transferring energy from the charger to a receiver in the back of the phone via electromagnetic induction. The charger uses an induction coil to create an alternating electromagnetic field, which the receiver coil in the phone converts back into electricity to be fed into the battery [8].

A copper coil is used to create an oscillating magnetic field, which can create a current in one or more receiver antennas. If the appropriate capacitance is added so that the loops resonate at the same frequency, the amount of induced current in the receivers increases. This is resonant inductive charging or magnetic resonance; it enables power transmission at greater distances between transmitter and receiver and increases efficiency. Coil size also affects the distance of power transfer. The bigger the coil, or the more coils there are, the greater the distance a charge can travel [9].

B. Matching Network

A matching network, also called an impedance transformer, is used to create matched impedance between a source and a load. Resonant topology studies mostly concentrated in the primary side, but less for the secondary side in the present literature. For the secondary side, series and parallel topologies are the most basic [10-12]. The parallel topology presents a boosted voltage to the load but reflects reactive loads back onto the primary side. The series topology eliminates this problem, but the output power is relatively low because of the low open-circuit voltage [11].

As the series and parallel topology alternatives, inductor-capacitor-inductor (LCL) and inductor capacitor-capacitor (LCC) topologies are the most widely used [11-14]. For these topologies, the reactive power at the secondary side could be compensated to form a unity power factor pickup, and an additional capacitor added in series with the pickup coil can be thought of as a current boost [13]. However, both the LCL and LCC topologies are current source characteristics [14]

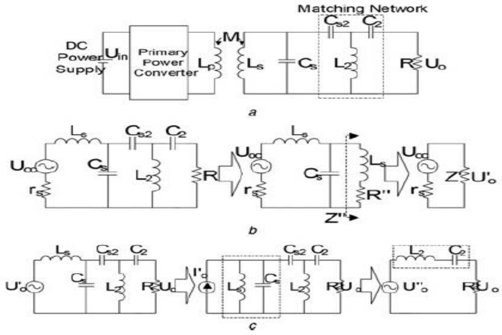

Figure 3. Analysis of the proposed parallel-T structure: (a) Schematic of the proposed WPT system; (b) Analyses from impedance transformation view; (c) Analyse from circuit transformation view

and it needs a voltage-source output on the secondary side. A T-matching network in parallel connection with an inductor-capacitor (LC) parallel circuit makes it work as a voltage boost, makes it possible to transfer more power under weak coupling conditions [3].

C. Single Transmitter and Multiple Receivers

For a wireless power transmission to multiple receivers to be feasible, each receiver must be made of coils smaller than the transmitter [15]. Therefore, they were kept within the region where the magnetic field from the source coil is relatively uniform. Additionally, the receivers should be spaced far enough apart to ensure that the interaction between any two of them has a negligible impact on their interaction with the source coil. Hence, the normal resonant coupling interaction between source and receiver should suffer minimal impact from the mutual inductance between any two receiver coils [4, 16].

When strongly coupled interactions occur between any two receivers, the single-transfer function resonant peak splits into two distinct peaks. As a result, the resonant circuits have to be tuned to one of these new frequencies before power can be transferred to them [17].

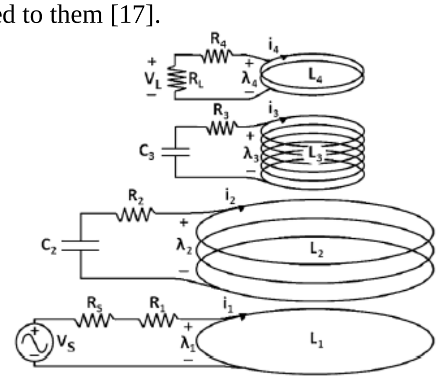

Figure 4. Schematic of a Multiple Receiver System

3. Methodology

A. Modeling of Resonant Inductive Coupling Wireless Power Transmission

According to the Figure 5, coefficient of mutual induction is defined as the ratio of magnetic flux in receiver coil to the current in transmitter coil [8]. Two coils are considered close to each other where the first coil connected to the voltage source of variable e.m.f or alternating current (AC) source. Meanwhile, the second coil connected to the load or galvanometer. Coefficient of mutual inductance will depend on the shape and size of the coil . Furthermore, the medium between the coil can also affect the value of coefficient between the transmitter and receiver coils [8].

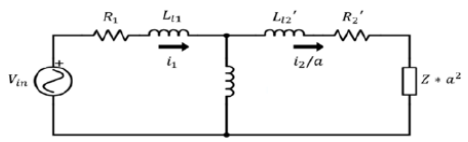

Figure 5. T-model

Coefficient of coupling effects the mutual induction between the two coils by relative orientation of the coil. In other words, the method of joining the two coils effect mutual induction. The amount of flux generated by the first coil is hundred percent linked with the second coil [8].

The circuit of single transmitter with multiple receivers as shown in Figure 6 is the chosen for this project. There are two modules in this circuit which are transmitter module and receiver module. Each receiver is connected with matching network and also mutual inductors on the secondary side. In this project, a resonant wireless power transfer system with the transmitter and receiver coils are directly connected to both the source and load respectively. Moreover, same resonant frequency is achieved by assuming using identical resonant coils of same diameter and material.

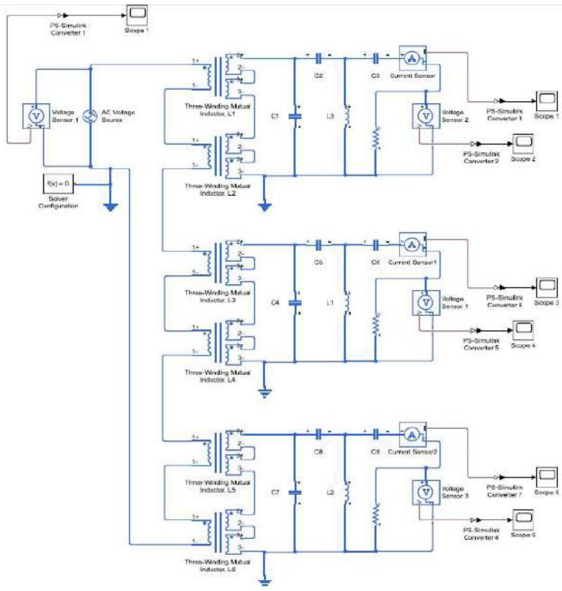

Figure 6. Circuit with Multiple Receivers

In the primary side of transmitter module, alternating current (AC) power is connected and a resonant frequency is produced from AC current. The receiver module at secondary side of wireless power transfer system is picking up all of its power from the magnetic field that is generated by the transmitter module to the each of receiver that consists of receiving coil.

B. Parameter of Circuit

The value of each parameter is important as it will affect the output wave of result. Firstly, the voltage source is set as 400V in the input. The frequency is then adjusted until it is suitable to be used. For this project, the frequency is starting about 50kHz. The value of parameters can be changed into suitable value until the simulation shows good results. Value of parameters are adjusted with the references from conferences and technical papers.

Table 1 below represents the parameters for overall circuit with multiple in Figure 6 Value of frequency and voltage is set as 50kHz and 400V respectively in the input. Values for parameters in receiver module are same for all receivers' part.

Table 1. Parameters for circuit with multiple receivers

Components	Value
AC Voltage Source Frequency	50kHz
AC Voltage Source Voltage	400V
Three-Winding Mutual Inductor, L1, L3 and L5	20.58μH
Three-Winding Mutual Inductor L2, L4 and L6	14.29μH
Resistor	2Ω
Capacitor, C1, C4 and C7	492.4ηF
Capacitor, C2, C5 and C8	60.8ηF
Capacitor, C3, C6 and C9	54.12ηF
Inductor, L1, L2 and L3	130μH

4. Results and Discussions

Figure 7, Figure 8 and Figure 9 are simulation result of output voltage with frequency of 50kHz at three receivers.

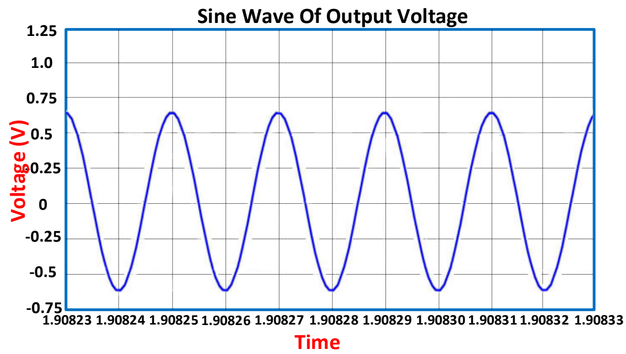

Figure 7. Sine Wave of Output Voltage (Receiver 1)

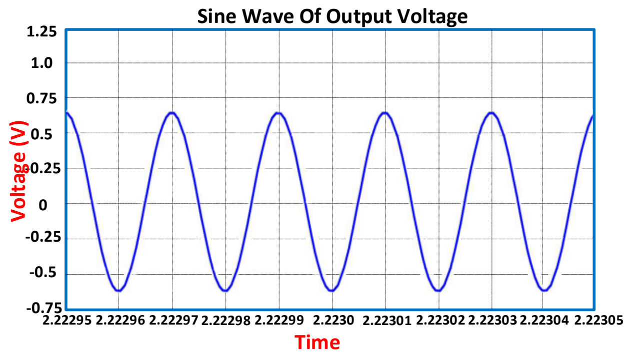

Figure 8. Sine Wave of Output Voltage (Receiver 2)

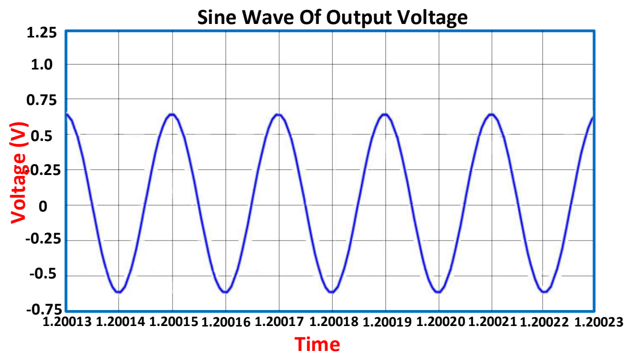

Figure 8. Sine Wave of Output Voltage (Receiver 3)

The values of output voltage in Figure 7, Figure 8, and Figure 9 with frequency of 50kHz are 603.118mV, 605.494mV and 606.996mV respectively. Based on the simulation result, output voltage for three receivers is about same.

On the other hand, Figure 10, Figure 11 and Figure 12 are simulation result of output current with frequency of 50kHz at three receivers

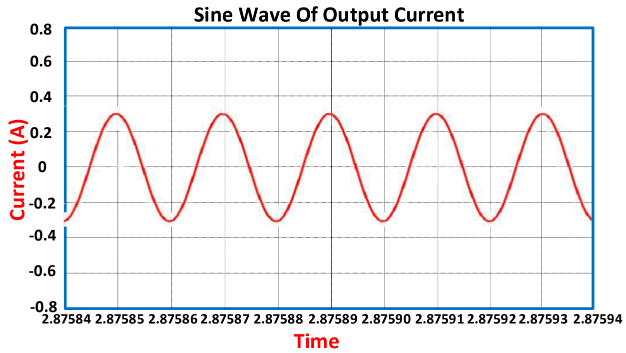

Figure 9. Sine Wave of Output Current (Receiver 1)

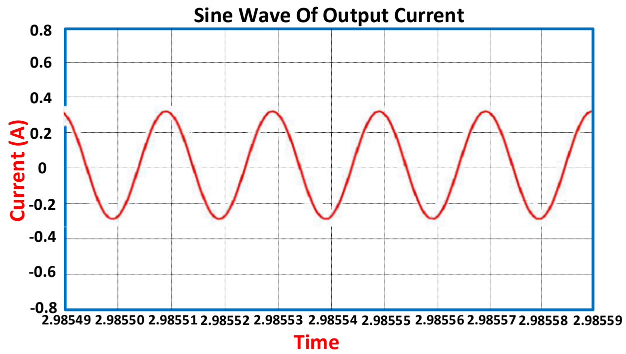

Figure 10. Sine Wave of Output Current (Receiver 2)

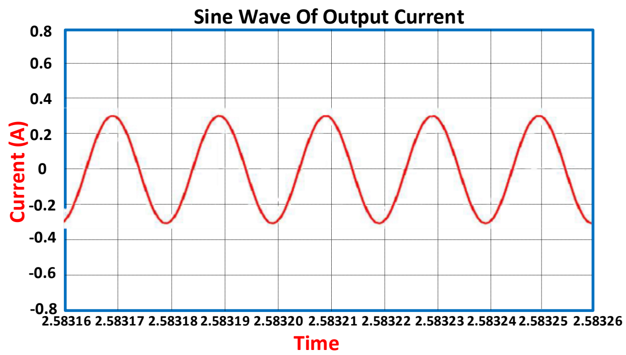

Figure 11. Sine Wave of Output Current (Receiver 3)

The values of output current in Figure 10, Figure 11, and Figure 12 with frequency of 50kHz are 302.305mA, 303.594mA and 303.961mA, respectively. Based on the simulation result, output current for three receivers is about same.

Figure 13 and Figure 14 below show the graph of total output voltage and power respectively for all receivers with different value of frequency starting from 1kHz, 10kHz, 50kHz, 100kHz, 250kHz and 500kHz.Value of power is calculated based on the equation (1).

$$P = I \text{ x } V \tag{1}$$

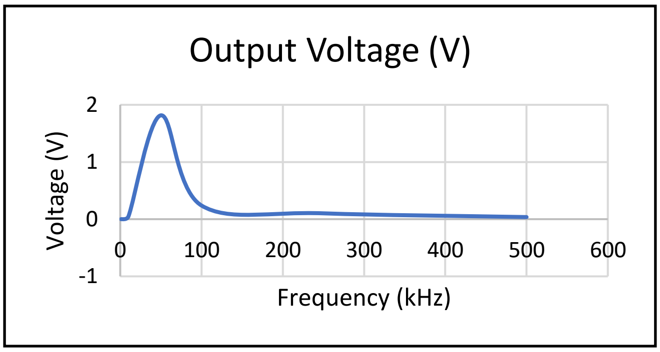

Figure 11. Graph of Output Voltage against Frequency

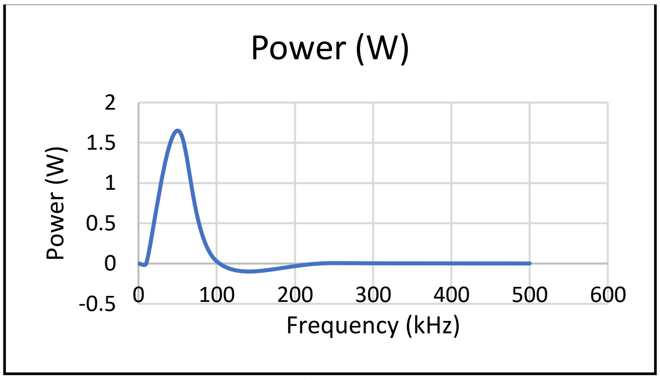

Figure 11. Graph of Power against Frequency

6. Conclusions

Output voltages and power have investigated using suitable frequency and parameters. The model of Wireless Power Transmission (WPT) has design through Resonant Inductive Coupling. Other than that, WPT system and also principle of magnetic wave between transmitter and receiver have developed with related parameters. Wireless power transfer has got more attention from researchers and inventors because this technology has opportunity to change many things in the daily lifestyle as well as the industrial sector [16]. Delivery of electric power wirelessly to device using resonant inductive coupling promises greater level of convenience to users of portable devices, and eliminates the environmental threat posed by bad cord and cable disposal [5]. The wireless power transfer for resonant inductive coupling has been successfully created and simulated by using MATLAB Simulink software. Parameters such as mutual inductors and coupling coefficient are determined for induction coil. Furthermore, parameters like capacitors and inductors are analytically determined for matching network. The graph of output voltage and power are plotted with different value of frequencies to show the effect of frequency at transmitter to the receivers.

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References

[1] Sivagnanam, G., et al., *Wireless power transmission using inductive coupling.* Programmable Device Circuits and Systems, 2012. **4**(5): p. 260-263.

[2] Alhamrouni, I., et al. *Application of DC-DC converter for EV battery charger using PWM technique and hybrid resonant*. in *2016 IEEE International Conference on Power and Energy (PECon)*. 2016. IEEE.

[3] Guo, Y., et al., *Resonant enhanced parallel-T topology for weak coupling wireless power transfer pickup applications.* The Journal of Engineering, 2014. **2015**(7): p. 223-225.

[4] Atayero, A.A., et al., *Development of a wireless power transfer system using resonant inductive coupling.* 2016.

[5] Salem, M., et al., *A review of an inductive power transfer system for EV battery charger.* European Journal of Scientific Research, 2015. **134**(1): p. 41-56.

[6] Cook, D.M., *The theory of the electromagnetic field.* Englewood Cliffs, 1975.

[7] Moliton, A., *Basic electromagnetism and materials*. 2007: Springer Science & Business Media.

[8] Alhamrouni, I., et al., *Application of inductive coupling for wireless power transfer.* International Journal of Power Electronics and Drive Systems, 2020. **11**(3): p. 1109.

[9] Park, Y.-J., et al., *Innovative Wireless Power Receiver for Inductive Coupling and Magnetic Resonance Applications*, in *Wireless Power Transfer-Fundamentals and Technologies*. 2016, IntechOpen.

[10] Wang, C.-S., O.H. Stielau, and G.A. Covic, *Design considerations for a contactless electric vehicle battery charger.* IEEE Transactions on industrial electronics, 2005. **52**(5): p. 1308-1314.

[11] Keeling, N.A., G.A. Covic, and J.T. Boys, *A unity-power-factor IPT pickup for high-power applications.* IEEE Transactions on Industrial Electronics, 2009. **57**(2): p. 744-751.

[12] Li, S., et al., *A double-sided LCC compensation network and its tuning method for wireless power transfer.* IEEE transactions on Vehicular Technology, 2014. **64**(6): p. 2261-2273.

[13] Huang, C.-Y., J.T. Boys, and G.A. Covic, *LCL pickup circulating current controller for inductive power transfer systems.* IEEE transactions on power electronics, 2012. **28**(4): p. 2081-2093.

[14] Madawala, U. and D. Thrimawithana, *A bidirectional inductive power interface for electric vehicles in v2g systems, Industrial Electronics.* IEEE Transactions on. **58**(10): p. 4789.

[15] Salem, M., et al., *Resonant power converters with respect to passive storage (LC) elements and control techniques–An overview.* Renewable and Sustainable Energy Reviews, 2018. **91**: p. 504-520.

[16] Salem, M., et al. *Phase-shifted series resonant DC-DC converter for wide load variations using variable frequency control*. in *2017 IEEE Conference on Energy Conversion (CENCON)*. 2017. IEEE.

[17] McSpadden, J.O. and J.C. Mankins, *Space solar power programs and microwave wireless power transmission technology*. IEEE microwave magazine, 2002. **3**(4): p. 46-57.