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A DEVELOPMENT OF ELECTRICAL VEHICLE CHARGING SYSTEM USING WIRELESS POWER TRANSFER

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ABSTRACT

Wireless power transfer is a method of transferring electrical energy from power source to electrical load without any wire connections. It is used to supply the power on electrical devices without any physical connection except air as the medium transfer. In this paper, the design of wireless power transfer charging system for electric vehicles using inductive resonance coupling method will be presented. The purpose of this project is to develop a prototype of electrical vehicle (EV) charging system by wireless power transfer using inductive resonance coupling method. Besides, the performance of wireless power transfer prototype using this method will also investigate. This paper are carried out with the theoretical studies of inductive resonance coupling method, design proposed, circuit simulation and prototype development. The prototype were consists of a few components which are power supply, transmitter/receiver coil with circuits and charging circuit for EV battery. Observation from the prototype experimental show that, power supply can be transfer wirelessly through transmitter and receiver circuit using inductive resonance coupling principles. Other than that, the performance of electrical vehicle charging system are depends on distance of transmitter and receiver coils, period of charging and amount of power sources.

Keywords: wireless power transfer, inductive coupling method, electrical vehicle, transmitter, receiver, magnetic coils.

INTRODUCTION

For an ancient, electrical energy has been distributed using conventional grid and cable which contributed in heavy line losses and obsolete infrastructure [1]. However, latest wireless technology has offer an electrical power to be distribute and transfer form one source to another without any physical contact. Apart from that, wireless power transfer also offers convenient, reliable and safety power transmission and the most importance reduce power losses [2, 3].

Concept of wireless power transfer has been discovered widely since Nikola Tesla carried out his first experiment about pursuing his idea on wireless lighting and electrical distribution after successfully invent an alternating current [1, 4, 5]. Thereafter a great interest and investigation on that area began. According to working principles, wireless power transfer technology can classified into few method of principle such as microwave, laser, photoelectric, radio waves (RF), magnetic resonance and inductive coupling method [5, 6-8]. Based on the power transfer distance wireless energy transfer methods can be categorized into two types; near field and far field. Laser, photoelectric, RF and microwave can be considered as far field energy transfer methods while inductive coupling and magnetic resonance coupling are based as near field approaches. This typical inductive power transfer (IPTS) schemes are limited to a few centimeters [9].

Current technology of electrical vehicles charging allow EV battery charges by plug-in cable source into receptacle on the vehicle [9]. However, this conventional method will exposed EV owner to physical and safety hazard such as electrocution due to poor aesthetic system and inconvenient charging situation [10-12]. Therefore a convenient, affordable and safety station to charge EV are required. The availability of charging station at home, workplaces and public destination may support the market acceptance of this EV in future [13]. Besides, it is an emerging technology to reduce fuel usage and greenhouse emission [14-16].

Wireless power transfer for electric vehicle charging system would be a convenient feature of solution for this matter. The process is fully automated, whereby no human handling works are required to perform the charging process. The concept of this project is suitable for any electric vehicles such as bus, car and light train. It will prepare a new convenient way to recharge the battery of the electric vehicles rather than using the traditional plug-in cable. WPT technology can be used as a solution in eliminating many charging hazards and drawbacks related to cables.

There are two concept enabled in EV charging system; stationary and dynamic. Stationary WPT can replace the charging cable for PEVs whereby activated when vehicle reaches to the charging area. While the concept of dynamic WPT charged while vehicle is moving in a road. This particular concept will increase the effective driving range while reducing the volume of battery storage however required large area and costly [9]. Modeling methods and desiging challenge has their own merits [9] therefore, this paper will focus of development of stationary EV charging system through wireless power transfer using inductive coupling principle. It provides a background of wireless power transfer specific in inductive coupling principle, develop the system with a simple circuit and design the EV charging system in a small scale prototype, nevertheless the performance of system will also be studies.

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CONCEPT AND DESIGN

The inductive resonance coupling principle is a combination of inductive coupling and resonance frequency produced by the alternator. It is due to resonance characteristics which are directional comparable to inductive coupling.

Inductive coupling system basically refers to two resonant circuits that have the same frequency and placed interfaces each other. When both circuit are given with supply there is a tendency of power transmission from one object to another object [3, 17, 18] known as mutual inductance around 10% of the total inductance [19]. The exchange energy will occur efficiently with small energy dissipated due to unrelated of resonant objects [20]. Inductive coupling technique does not rely on propagating electromagnetic, waves. Besides, this method is more safety and reliable to be uses in our prototype.

In this paper, inductive coupling principle are made up from two air copper coil that acts as transmitter and receiver. The coil will placed interfaces each other to allow power transmit through air or known as wireless method. The receiver circuit is then connected to the battery circuit charging to charge the EV battery system. Therefore, the EV charging system in this paper were consists of a transmitter, an air core inductor of transmitter and receiver with copper coil. The transmitter produces a non-radioactive magnetic field resonating at KHz or MHz frequencies and the receiving unit resonates it in their areas.

Figure-1 shows the block diagram of wireless power transfer prototype for electric vehicle charging system. Two major component that have been produced in this system is the multilayer air core inductor made up from copper material as transmitter and receiver coil. This system are divided into five block such as dc power supply as power sources, oscillator, transmitter coil, receiver coil, rectifier and load (battery).

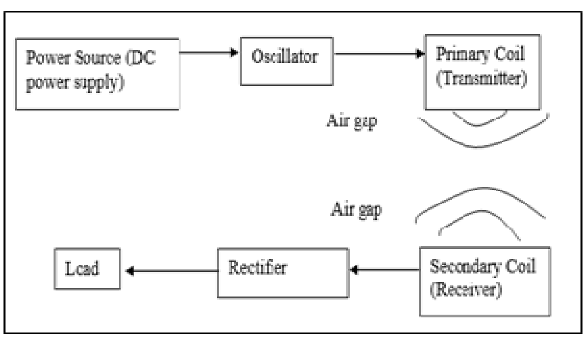

Figure-1. Block diagram of EV charging system.

When AC power is supplied through transmitter coil, magnetic field will induced around the coil. Since the receiver coil is placed facing it, the current will induced and caused the magnetic field generate at the receiver coil. The received AC current will then convert into DC current to charging the load or EV battery. This condition is known as inductive resonance coupling method whereby energy is transfer when both coils that have same resonant frequency placed interfaces each other.

CIRCUIT DIAGRAM

Figure-2 and 3 represent the schematic circuit diagram of transmitter and receiver respectively. In transmitter circuit the inductance is put in series with coupling inductance of the system. The purpose for having a series capacitance L_1 in the circuit is to cancel the leakage (or self) inductance, so that all the voltage in the primary winding, will applied in the mutual inductance. Meantime, the secondary winding in the receiver depicted in Figure-3 will receives the fully input without any drop voltage. The transmitter circuit are consists full bridge rectifier, reactance and capacitance for the full voltage applied to the load device during resonance. Receiver resonator is connected to the load through a battery charging circuity. In EV charging system battery is connected through a rectifier and regulator circuit. Load impedance consists of the impedance of the charging circuitry. Battery load can be approximated to a resistive AC load [19].

This circuit can be used to obtain the equations of input and output voltage. The efficiency of the system are depends on mutual inductance, load resistance (equivalent to the resistance of battery), primary impedance, secondary impedance and power factor. Instead of series-series resonance circuit, the series-parallel topology can also be used which reportedly has the advantage of secondary acting as current source for battery charging

Multisim software was used to ensure the proper operation and connection for the circuit. By computer simulations, variations of the parameters such as magnetic field, total flux and interaction of the human body to the field for different physical parameters of the system can be generated and analysed. The development of full circuit on Printed Circuit Board (PCB) was done after the breadboard circuit measured and preliminary tested were succeed.

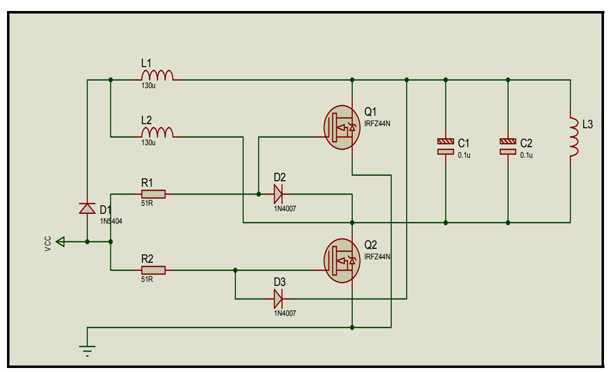

Figure-2. Schematic diagram for transmitter circuit

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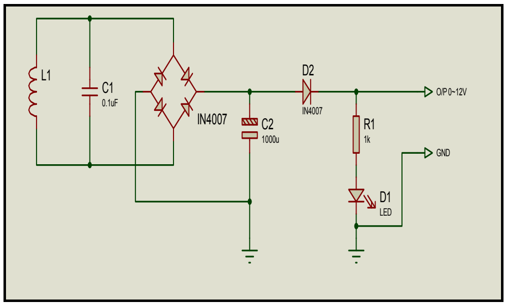

Figure-3. Schematic diagram for receiver circuit.

Various IPTS systems have been proposed for stationary or static and dynamic charging of electric vehicles wirelessly since 1990s including those developed by Auckland University [21-24]. A circular or rectangular type coil is used as the primary coil with various secondary coils (such as circular types or double sided types and single-sided polarised coils with an additional coil) for enhanced performance for high power transfer. Circular coils have a benefit of a compact structure, lower weight and lower electromagnetic field (EMF) but limited by power transfer capacity and less lateral tolerance. Hence, rectangular core plates have potentially higher coupling factors and large lateral tolerances but has advantages such as simple and convenient to develop [19]. The transmitter coil is wound with 12 turns of enamelled copper wire in 18 AWG and about 7 meter length to form circular coil. The radius of the completed transmitter circular ring coil is 6.5 cm with depth of 0.1 cm. All turns have the same diameter. The receiver coil consist of 16 AWG diameter copper wire, wounded in 14 turns with radius of 9 cm. The depth wire used for the construction of receiver circular coil is 0.05 cm. Signal is fed to the transmitter coil and power transferred to receiver coil. The resonance frequency can be calculated as [25]:

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

The development of transmitter and receiver coil is built using wheeler formula to get the inductance value [26] as below.

$$L = \frac{0.8r^2N^2}{6r + 9l + 10d} \tag{2}$$

The variation of coupling coefficient with coil alignment for different coil designs give better response for misalignment is a good choice for the efficient power transfer in real conditions [19].

RESULTS AND DISCUSSIONS

The developments of designed circuit are successfully fabricated on PCB. Figure-4, illustrates the succeed prototype of transmitter and receiver coil with operational circuit. Observation from the experiment set up show that, power from power supply can be transfer wirelessly through transmitter circuit and receiver circuit using inductive resonance coupling principle. The white LED is lighten up on receiver circuit indicate the presence of voltage and current

Using the DC power supply as power source, the input voltage and current are set-up to various input power (P = VI), to investigate the voltage output of the prototype model. There are two parameter that affect output voltage and current such as distance between transmitter coil and receiver coil to transfer the power (watt) and amount of power value given to the transmitter.

Figure-5 depicted the effect on the voltage and current on receiver circuit with different distance of coil. The power supply is fixed with 15 V and 0.81 A. From the observation, the amount of voltage and current is decreases simultaneously with the increases of distance. The wider the distance between two coils, the lower voltage and current can be received. This phenomenon occur due to the magnetic field that become weak when the distance increases between transmitter and receiver coil. Therefore, less power can be transfer from transmitter to the receiver coil if the distance between them getting wider [19].

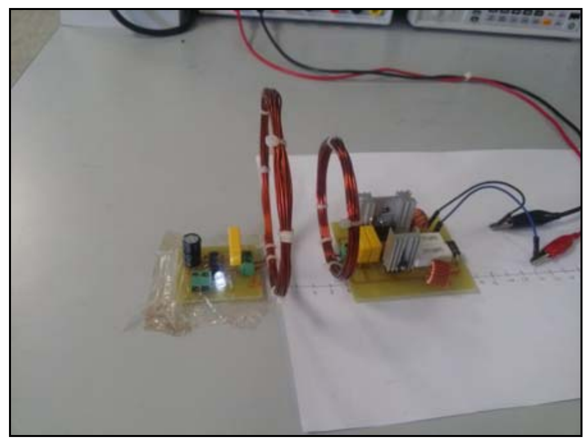

Figure-4. Prototype of transmitter and receiver coil with operational circuit.

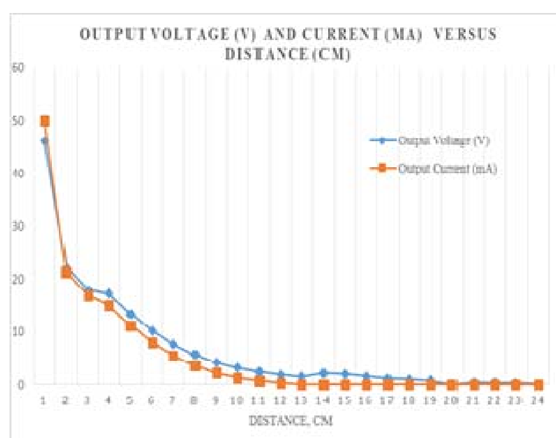

Figure-5. Effects voltage and current at various distances.

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Figure-6 illustrated the effect of output voltage versus input voltage at the distance of 0, 5, 10, 15 cm. The data shows that when input voltage increased, the output voltage also increased. Obviously, when the distance between transmitter and receiver coil is 0 cm, the output voltage is higher than input voltage. This is due to transmitter coil has less number of turn than receiver coil. In this situation, the principle of step up transformer can be applied on magnetic resonance coupling. As the distance is increased to 5 cm, output voltage value is decreased lower than input voltage because air resistance exist between transmitter and receiver coil thus the magnetic field get weaker. This is the recommended range for this prototype to power up the low voltage electrical devices like rechargeable battery. But the distance range above 5 cm is not recommended because there are no current transferred at this distance. Figure-6 also shows that when the amount of input power increases, the output power will also increases respectively.

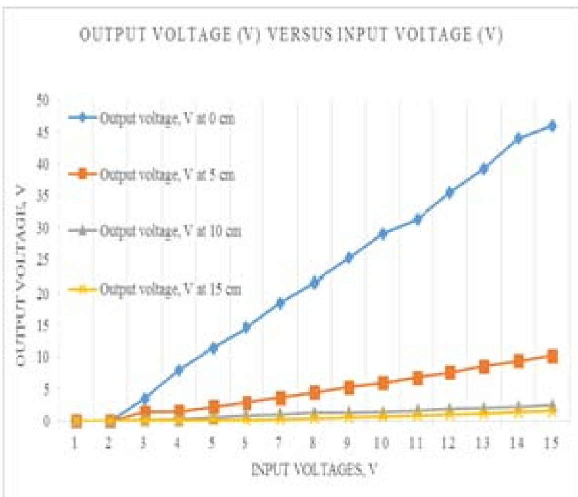

Figure-6. Output voltage at various distances range.

Figure-7 represents the impact of output voltage due to different type of barrier and distance. From the observation, soil and water does not affect the output receiver but when a metal such as aluminium is placed between the coils, the power cannot be transmit. Its show that, metal has a capability to cut the magnetic field linked between two coils. This research proved that inductive resonance coupling is the most suitable method to charge electric vehicles wirelessly because obstacles like water and soil are the commonly found under the vehicle

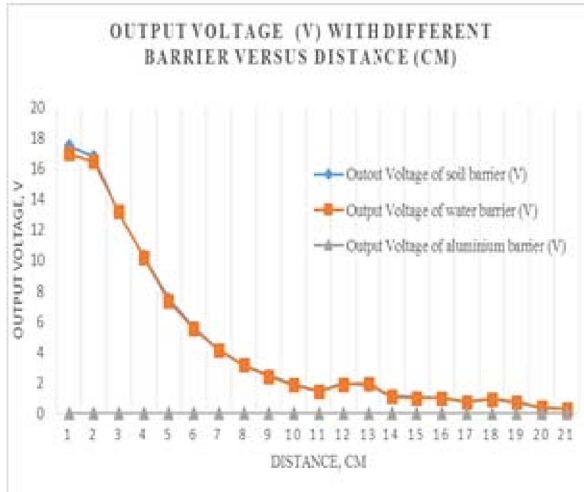

Figure-7. Output voltage due to various distances range and barrier types.

Figure-8, display the electric vehicle prototype with rechargeable lithium battery. As shown in Figure-8, there are no physical connection between power supply and electric vehicle. The transmitter coil (small diameter coil) is located at the bottom of the vehicle prototype, while the receiver coil (big diameter coil) is placed on the vehicle prototype. When the vehicle park on top of the charging coil, the energy can be transmitted wirelessly between those two coils, whereby the lithium battery is charging. However the battery charging ability is very slow because the output is too low. The maximum output measured at receiver was only 46V, 50 mA with input power of 15V, 0.81 A.

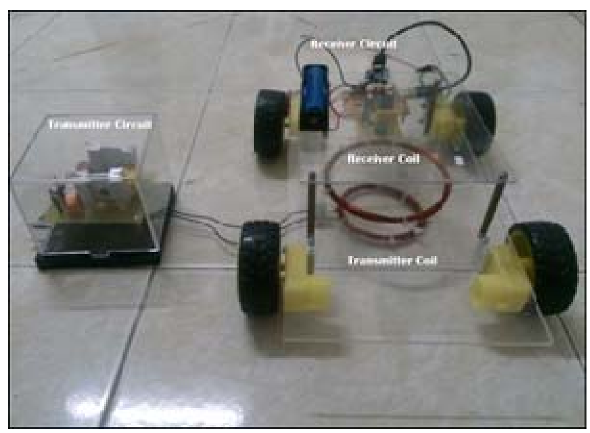

Figure-8. An electric vehicle prototype integrated with wireless power transfer device.

CONCLUSIONS

In this paper, a prototype of EV charging system by wireless power transfer using inductive resonance coupling principle was successfully developed. The performance of the prototype was also observed and measured. Observation showed that there are three parameter influenced the EV charging performance hence,

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distance between transmitter and receiver coil, amount of input power and period of charging. The performance of this device is applicable to charge low power electrical appliances effectively within the distance range not more than 5 cm. Although the performance of the prototype are very slow to charge the real EV charging system, this paper has proven that by using inductive resonance coupling principle as wireless power transfer, electric power can be transfer from one system to another system respectively.

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