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Wireless EV Charging by The Concept of Magneto Resonant Coupling

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Abstract— **To increase the usage of electric vehicles (EV), a safe and convenient method to charge the vehicles is essential. Wireless power transfer (WPT) technology makes it possible to supply power through an air-gap, without the need for current-carrying wires. One important technique of WPT technology is magnetic resonant coupling (MRC) WPT. A typical magnetic resonance coupling based wireless Electric Vehicle (EV) charging system consists of a transmitting coil at the charging station and a receiving coil in the vehicle. In order to maintain good energy transfer efficiency of the wireless charging system, the effect of the proximal metallic object in the vicinity of the receiving coil has been investigated. By experimental measurement, it has been observed that the resonance based wireless energy transfer system is very sensitive to the nearby metallic objects, leading to significant deterioration in energy transfer efficiency. This effect on the energy transfer efficiency is also seen to be different for different physical spacing between the transmitting and receiving coils. It is also found that the operating resonant frequency for optimum energy transfer efficiency changes with the metallic object in close proximity to the receiving coil. The advances make the WPT very attractive to the electric vehicle (EV) charging applications in both stationary and dynamic charging scenarios. This paper reviewed the technologies in the WPT area applicable to EV wireless charging. By introducing WPT in EVs, the obstacles of charging time, range, and costcan be easily mitigated.**

I. INTRODUCTION

Wireless charging systems for EVs have recently received much attention because the wireless charging can provide the convenience to power EVs wirelessly [1, 2]. Roadway electric vehicle applications using conventional inductive coupling [3, 4] and microwave energy transmission [5] have been proposed for more than two decades, but till date there has been only limited commercial development due to the difficulties of inconvenience and efficient only for very short range distance. As electric vehicles make use of large amounts of energy, any loss in energy efficiency due to the energy transfer process from the source to the vehicle, will be significant. It has been found that magnetic resonance coupling based wireless energy transfer system is an effective solution of powering or charging an EV wirelessly

. As a result of the advantage of being efficient over a relatively far distance, the magnetic resonance coupling based wireless energy transfer system has been utilized for charging EVs. In order to make the magnetic resonance coupling based wireless EV charging system more viable, it is important to investigate the effect of surrounding metallic objects along with the operating parameters on the energy transfer efficiency of the wireless charging system.

In this paper, the effect of operating parameters such as the operating frequency, physical spacing, and proximal metallic object on the wireless energy transfer efficiency and classification of wireless EV charging have been investigated.

II. WIRELESS CHARGING DESIGN , OPERATING CONDITIONS AND MECHANISM

The experimental setup of wireless energy transfer system based on magnetic resonance coupling for charging of EVs is shown in Fig. 1(a). The wireless energy transfer system consists of a Radio Frequency (RF) power source, driving coil, transmitting resonant coil, receiving resonant coil, load coil and resistive load. The input RF power source is supplied to the driving coil. The transmitting coil is inductively coupled with the driving coil so that the transmitting coil is energized at its resonant frequency. The receiving coil is magnetically coupled at its resonant frequency with transmitting coil placed away from each other. The strong magnetic field coupling between the transmitting and receiving resonant coils enables the energy to be transferred from one coil to the other at the operating resonant frequency over a relatively large distance. The load coil is inductively coupled with the receiving coil. The received energy is then transferred to the load coil, and finally delivered to the load resistance connected across the load coil. In the magnetic resonance coupling based wireless energy transfer system, electromagnetic resonance coupling entails an LC resonance. The LC resonance occurs at a particular frequency called resonance frequency at which the inductive reactance ($X_L = 2\pi fL$) is equal to the capacitive reactance ($X_C = 1/2\pi fC$), leads to the maximum energy transfer from the transmitting coil to receiving coil. The resonant frequency (f) of the transmitting and receiving coil is determined by the well known formula [3] .

$$f = 1/2\pi\sqrt{LC} \quad (1)$$

The experimental energy transfer efficiency depends on the input supply power (Pin) and the output power (Pout) delivered to the load resistance connected across the load coil. The efficiency is given by:

$$\eta(\%) = (P_{out} * P_{in}) \times 100 \quad (2)$$

The wireless energy transfer is based on the strongly coupled magnetic resonance mechanism [3]. When the resonant transmitter and receiver coils are in the midrange proximity (distance equal to several times of resonant coil

Hardware:

size) their near fields will strongly couple with each other. The strong magnetic field coupling between the resonant coils allows the energy to be concentrated at a specific resonant frequency to transfer from one resonating coil to the other placed away from each other even over a relativelyfar distance. This coupling mechanism enables the receiver resonant coil to capture energy efficiently from the magneticfields generated by the resonant transmitting coil.

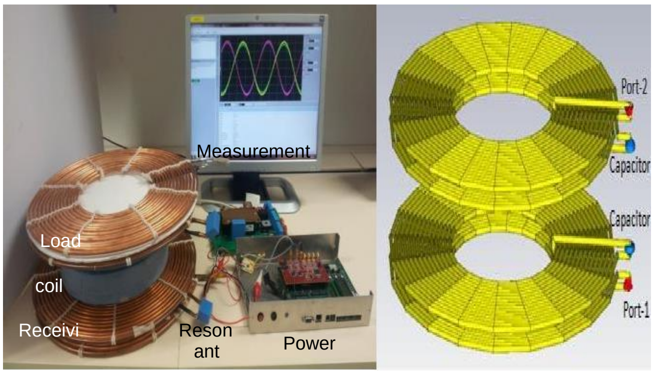

Fig.1: Magnetic resonance coupling based wireless energy transfer system for EV charging. wireless energy transfer system for EV charging.

III. System Description

Energy Coupling: Energy coupling occurs when an energy source has a means of transferring energy to another body. One simple example is a locomotive hauling a train car the mechanical coupling between the two enables the locomotive to haul the train, and overcome the forces of friction and inertia that keep the train can still the moves. Magnetic coupling occurs when the magnetic fields of one gadget. An electric transformer is a device that transfers the energy from its primary winding to its secondary winding, without the windings being connected to each other. It is used to "transform" AC current at one voltage to AC current at another voltage. Interacts with a second gadget and induces an electric current in or on that gadget. In this way, electric energy can be transferred from a energy source to a powered device. In divergence to the example of mechanical coupling given for the train, magnetic coupling does not require any physical contact between the gadget generating the energy and the gadget receiving or capturing that energy.

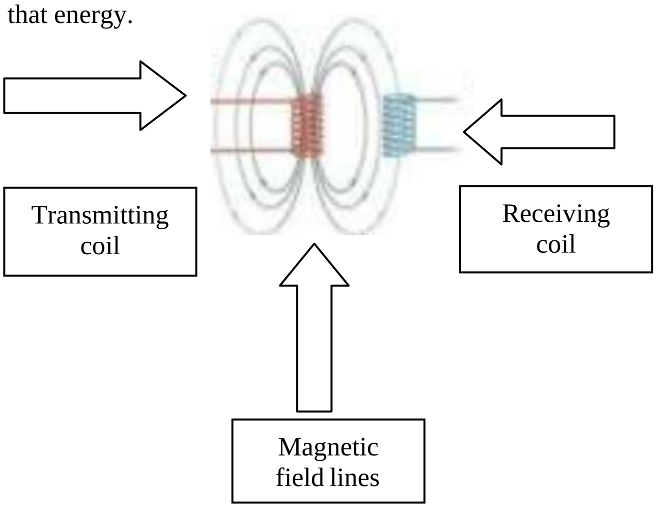

Fig.2: inductive loosely coupled coil

wave at the gate input. The voltage given to the transmitting coil generates the magnetic field around it. The capacitor is connected to the coil parallel and hence the resonating circuit is formed. Until the resonant frequency of receiving coil matches with the resonant frequency of the transmitting coil magnetic field won't get induced in the receiving coil. For this purpose of matching the resonant frequency we used different values of "L" and "C" for resonant frequency matching purpose. To match the resonant frequency of the receiver and the transmitter coil we used the switches to vary the time periods of the square wave by which we are controlling the frequency at output.

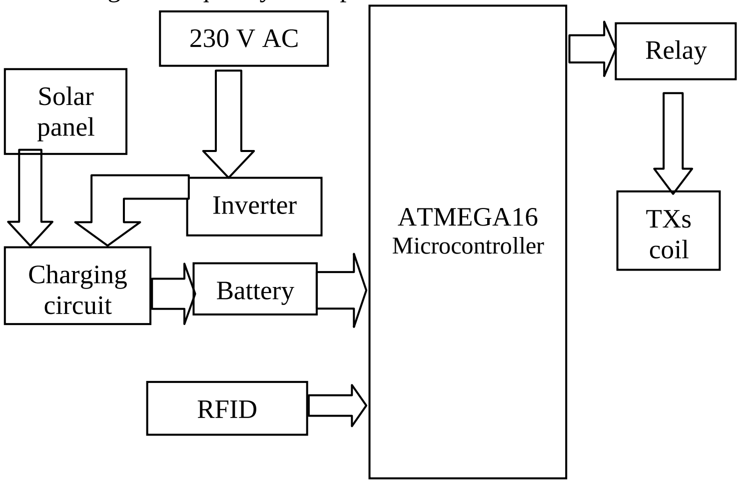

Fig. 3: Transmitter circuit

Receiving Circuit:

As the receiving coil comes in the range of the magnetic field of the transmitting coil, the voltage across the transmitting coil induced in the receiving coil because of mutual inductance and matching of resonance frequency. The received voltage is in AC form, we have to convert it into DC for DC load hence we used a rectifier circuit which provides constant DC at the output for driving the load. if the load is ac load then we can give direct output to it.

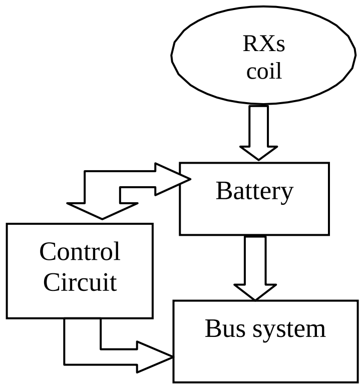

Fig. 3: Receiver circuit

Transmitter Circuit:

The input from mains is given to the power frequency controller. The output of this system is given to MOSFET/IGBT. The main purpose of using MOSFET/ IGBT is to convert DC to AC and also for amplifying square The main objective of the project was to develop a device for wireless power transfer. The device had to be an electronic circuit. The achievement of this objective was

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further broken down into specific objectives which all together aided the development of the device. The otherobjectives were as follows:

1. Design and assemble power supply unit :
The power supply was to step down 230V ac supplied by the mains to 12V ac high frequency. The 12V ac was then to be rectified to give 5V dc.

2. Setup DC supply ;
Using a boost converter, the dc voltage was raised to 30V dc.

3. Design and assemble an appropriate oscillator:
For the project, a royer oscillator was found to be mostsuitable.

IV. Types Of EV Charging

In this section, we will discuss the basic two types of design of static wireless and dynamic wireless EVs charging systems.

A. Static Wireless charging:

The block diagram of a wireless EV charging system is shown in Fig.5. There are several constraints to the design of static wireless EV charging system, as below:

• Increase magnetic coupling as much as possible to obtain higher induced voltage.
• Increase PTE for given power capacity and cost.
• Make the model as compact as possible to fit a given spaceand weight.
• Manage changes in resonant frequency and coupling coefficient due to misalignment of pick-up position, and air-gap variation.

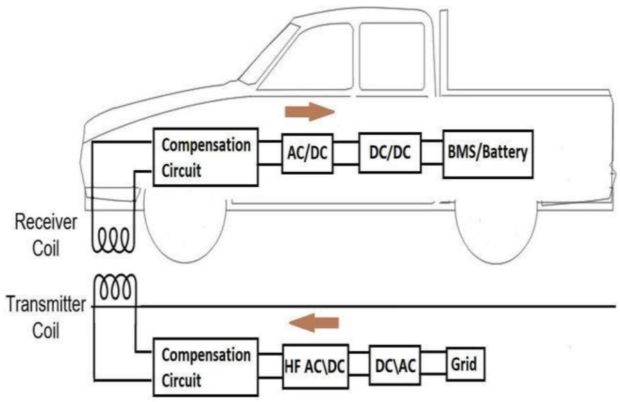

Fig. 5: Block diagram of the wireless EV charging system(static).

B. Dynamic Wireless Charging:

Even though dynamic wireless charging prototypes for EV are continuously proposed and improved upon for higher efficiency and lower costs, they are rarely commercialized and the existing commercial operations are limited to electric buses and trams, operating at low speeds in urban areas [8,9]. One of the potential reasons for this is the difficulty in precisely predicting and fast responding to the charging demands of an EV, particularly a private EV, for dynamic wireless charging systems.

Unlike the plug-in charging and static wireless charging, which normally lasts for hours at low power rating, the dynamic charging period varies from a few seconds to minutes, depending on factors including the driving speed, charging lane configuration and charging schedule [7]. Thus, dynamic wireless charging requires much higher charging power and faster balancing response from the charging system and power supply end [7, 10, 11].

V. Protypes Of MRC WPT

Many different schemes have been proposed for MRC WPT wireless charging systems. This section focuses on introducing the details of MRC WPT system design, which includes prototypes.

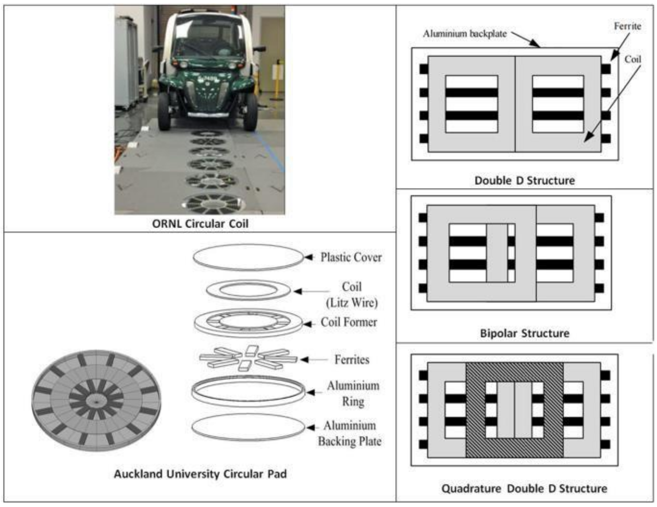

Fig. 6: Pad form in dynamic wireless EV charging system

Prototypes of MRC system:

According to the number of transmitters (TXs), MRC WPT systems can be classified as either single-input–single-output (SISO), single-input–multiple-output (SIMO), multiple-input–single-output (MISO) or multiple-input–multiple- output (MIMO). Fig.7. shows the difference between these four prototypes.

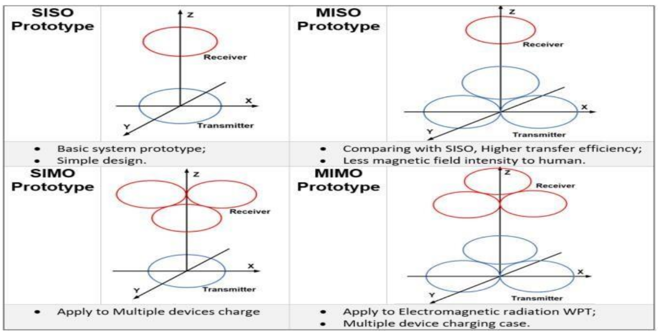

Fig. 7: Comparison of SISO, SIMO, MISO and MIMO

1. SISO and SIMO prototype: The SISO WPT is the most basic and simple prototype of the WPT systems. In a SISO WPT system, the receiver (RX) load plays an important role in the transfer function of the system. Moreover, the distance and orientation of the coils greatly affect the reflected load impedance on the TX side. In a MISO WPT system, due to the cross-coupling between the different TXs, the effects of the load on the transfer function and efficiencyof the system are increased.

2. MISO prototype: The scalability and behaviour of a SIMO system strongly depend on how the coupling between the TX and the RX, and the coupling between RXs, scale when the number of nodes is increased.

3. MIMO prototype: MIMO systems are always used in electromagnetic radiation WPT applications [12–14], e.g. wireless sensor networks. The exact resonant frequency between the TX and RX is necessary, so the MIMO systems are not widely used in MRC WPT technology.

VI. CONCLUSION

WPT technology is currently undergoing intense research in both academia and industry. MRC WPT plays an important role in WPT technology. Compared with other WPT techniques, MRC WPT has higher PTE with longer transmit distance. Meanwhile, there are several issues of MRC WPT, such as misalignment tolerance and load variation tolerance. High PTE is a common goal for all WPT techniques. By improving the design of the coil and circuit, the PTE can be improved. One important application of MRC WPT technology is wireless EV charging. There are two primary implementations of wireless EV charging, namely static wireless EV charging and dynamic wireless EV charging. Wireless EV charging technology can improve the user experience of EVs and offer greater flexibility. Dynamic wireless EVs charging can reduce the battery capacity requirement, extending the driving range of an EV. The future uptake of wireless EV charging faces several challenges including cost, standardisation, and health and safety.

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