SYNOPSIS

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Department: **Electrical Engineering Department (Faculty of Technology & Engineering)**
Thesis Title: **Induction Charging for Storage System of Hybrid Electric Vehicle.**
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1. Introduction:

Electric Vehicles (EVs) are now widely used as an alternative to the traditional transportation system due to the scarcity of petroleum products' availability. Over the past 20 years, numerous researches have been conducted to develop effective EV charging techniques [1]-[3]. A quick analysis of handful Wireless charging methods developed demonstrated that ICPT is a promising and convenient solution for EV wireless charging. The comparable circuit analysis and ICPT system characteristics are included in this study, which also focuses on the advancement of research into charging coil designs, leakage inductance compensation topologies, power level augmentation, and misalignment toleration. The deployment of EV charging has depended heavily on improvement of these characteristics [4]-[5].

The idea of wireless vehicle charging has attracted more attention than stationary wired charging technique [6][8][14]. Parking lots with wireless charging stations might guarantee that your car gets charged up to its time to leave the place [13]. Wireless charging facilities can be found on the conventional road network might even be positioned at crossroads or over longer stretches of highway, increasing the range of electric vehicles [16]-[18]. Other applications may profit from improvements in wireless energy transfer, such as the continual use of electric vehicles in a warehouse attributable to the installation of wireless charging tracks in the floor[15]-[16]. The achievement of wireless energy transfer system with simultaneous high efficiency and high power transfer over a range of airborne distances has, however, proven challenging.

2. Classification of Wireless Power Transfer Systems:

There are numerous varieties of wireless power transfer systems, depending on a number of factors. As you move closer to the radiating source, the EM fields take on a different form, which also affects wireless. They can be grouped into:

1. Near field
2. Mid field
3. Far field

The boundary between the zones is limited to one wavelength in the case of near field radiation. One to two wavelengths of electromagnetic radiation make up the transition zone,

which separates the two zones. The distance between the emitting source and the receiver in a far field is greater than twice the radiation's wavelength [2].
The following categories of wireless power transmission mechanisms [11] can be made based on how the transmitter and receiver are coupled:

1. Electromagnetic induction (Resonant Wireless Power Transfer)
2. Electrostatic induction (Resonant Capacitive Power Transfer)
3. Far field transfer techniques (Laser and Microwave Power Transfer)

WPT Technology Category	Advantages	Disadvantages
Inductive coupling	Sample, safe and high transfer efficiency in short distance	Short transmission distance, needs accurate alignment
Magnetic Resonant Coupling	Long transmission distance, no radiation	Difficult to adjust resonant frequency for multiple devices
Electromagnetic Radiation	Very high transmission efficiency over long distance	Radiation, needs line of sight

Table 1. Summary of advantages and disadvantages of different WPT technologies

WPT was first developed by Nikola Tesla, who undertook numerous tests on it at Colorado Springs, USA, in the 1890s [12]. To transfer energy between the receiver and transmitter WPT uses an air medium that will be electrified by charged particles as its receiver. An electric field, a magnetic field, or electromagnetic fields can all be used to transfer energy, depending on the applications, power ratings, and transmission range. The WPT techniques are split into near - field region and far field depending on the distance, as depicted in Fig. 1. Near field approaches are used to transmit energy over small distances, whereas far field strategies are used to transmit energy over greater distances.

Microwave beamforming, some of far field technique's approaches, has recently been applied in EVs and PHEVs. A model with an 80% RF-DC conversion efficiency that employs a roadside transmitter to fuel the EV was put forth [13]. This method has been employed in medium power applications, such charging portable electronics, for the past ten years. Near field transmission is safer for people to use because the electromagnetic fields implicated in far field techniques are stronger than those in the near field [14]-[16]. In order to account for this, the design of such a system model uses the near field transmission-related inductive power transfer (IPT) approach in WPT. Although the near field solutions have restrictions in terms of transmission range, poorer data rates, and sensitivity with regard to the locations of the transmitter and receiver, all aspects may not have an impact on performance in current applications that only need poorer data rates for short ranges. Several researchers claimed that these systems can also be helpful for achieving security [17].

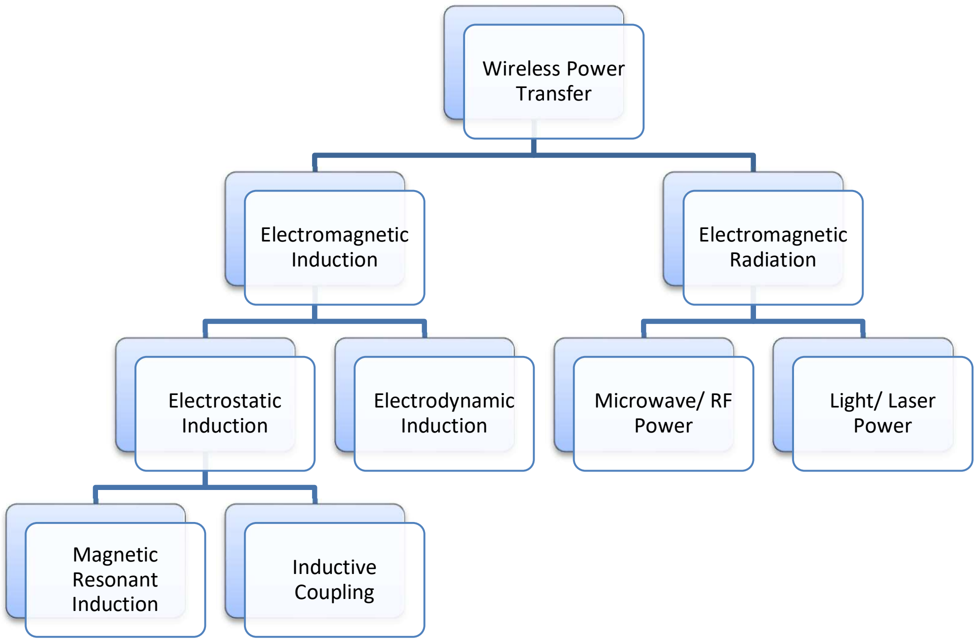

Fig 1: Examples of energy transfer in near field and far field

WPT is now used in many mobile devices, electric vehicles, and home appliances due to its benefits [18]. It's also employed in photovoltaic satellites and defence systems.

3. Inductive power transfer

In the current practical applications of near field transmission, there are two primary techniques that can be focused exclusively on coupling technology used within them. These coupling methodologies are outlined below.

1. Inductive Coupling
2. Capacitive coupling.

Inductive coupling is a near field technique in which energy is transferred between two coils using magnetic fields. The coils would be placed close together for transmission from sender to receiver. The mutual induction criterion is implemented to transfer energy between two coils without the use of a physical medium. When a current is passed through the primary coil, it generates a magnetic field over a short distance. When the receiver coil is in the vicinity of this field, voltage has been induced in it. Such an induced voltage has the potential to power a wireless device or maybe even a storage system. The magnetic field is used to transfer electrical power through one coil to another. Inductive coupling transfers energy between coils due to mutual induction. Figure 2 depicts a high-level overview of inductive coupling. A transformer is an excellent example of how mutual induction works because there is no contact between the primary and secondary coils.

Since inductive power transfer can maintain higher efficiency, it is employed in a variety of near field applications where it can manage a myriad of power loads without significant issues and with greater efficiency [14]. The distance between the transmitter and receiver as well as their mutual position affect the accuracy of the transfer. However, this method is only effective over short distance. The power transmission will indeed be reduced if the space between the coils is widened or if the secondary coil is positioned independently of the primary coil. Inductive coupling is still being developed for use in power transmission over larger distances [13].

There are important advantages that play a main role behind using the IPT technique in this system:

1. Environmental Friendly: Because IPT includes two individually enclosed sections, it can operate in severe situations. The effects of dirt, dust, or chemicals are minimal. It doesn't produce any carbon leftovers of any kind that could affect the environment. One concern about the magnetic influence on people was brought up in IPT. However, other studies conducted at the University of Auckland's medical school demonstrate that there are no detectable adverse biological consequences at low frequencies [15]. Unlike radio frequencies, these low frequencies typically lack the necessary power density to warm human body cells.

2. Robustness and Reliability: Since there is no direct friction in these systems, there isn't electrical deterioration or wear and tear. This system's electrical components are fully shut off, which prevents any form of chemical weathering in the conductor portions. As a result, less maintenance is needed.

4. Coil design

4.1 ANALYTICAL MODELING OF SQUARE COIL

The coils' circuit topology has transmitting and receiving coils and is represented by an analogous circuit that resembles an inductively coupled transformer, such as the one in Fig. 1. Imagine that the transmitting and receiving coils are placed in close proximity to one another, as shown in the image. When electricity flows through the transmitting coil, it creates a magnetic flux that connects the receiving coil in part [3][5]. Now, the coil's mutual inductance (MI) is displayed and determined using $M=\lambda_{12}/I$.

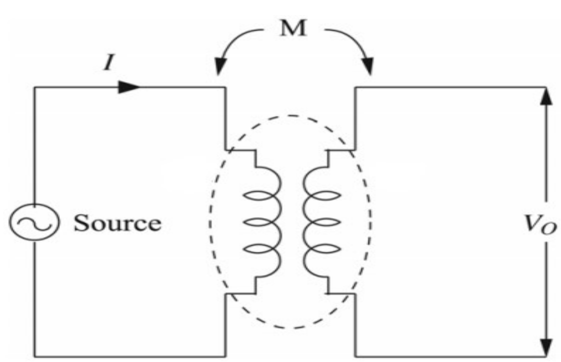

Fig.2 circuit topology of transmitting and receiving coil

The entire flux distribution can be found using the integration method of considering the whole coil as small coil of single turns [14]. The method can be used by using a tiny part of one turn of the entire coil. The flux linked by the tiny part can be considered for the calculation of whole coil and the mutual flux linked is estimated [12][8]. By repeating the process and more iteration, total flux linked with receiving coil can be found out. The sum of the flux linked in each little grid for all of the transmitting coils turns yields the total flux linked in the coil itself [7]. The maximum summation is determined by the quantity of tiny areas produced during a single OC turn. That can be calculate by considering the flux (φn) of all small regions (n^{th}) of a single turn of the coil.

4.2 DESIGN OF THE COIL PARAMETERS

Plane planner spiral coils having well coupling coefficient and quality factor, hence used for wireless power transfer.

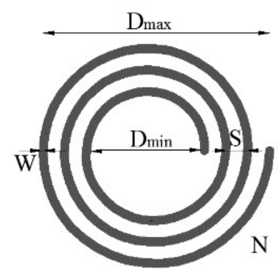

Fig.3 Circular coil

Here, D_{max} is the utmost outer diameter, D_{min} is the least inner diameter, N is coil turns, S is the distance among adjacent turns, and W is wire diameter.

$$D_{max} = D_{min} + (2N - 1)(S + W) + 2W \quad (1)$$

$$B = \frac{D_{max} - D_{min}}{D_{max} + D_{min}} \quad (2)$$

$$D_{avg} = \frac{D_{max} + D_{min}}{2} \quad (3)$$

The distance between two turns should be calculated by considering following conditions.

$$S < S_{1max} = \frac{D_{lim} - 2W}{2N - 1} - W$$

$$S < S_{2max} = \frac{2D_{lim} - (2W + 4r_{avg})}{2N - 1} - W$$

Where, S_{1ma} is allowable maximum coil internal spacing and $S_{2max}$is allowable maximum external spacing.

$$L = \mu_0 N^2 r_{avg} \left(ln \frac{2.46}{\beta} + 0.2\beta^2 \right) \quad (4)$$

$$R = R_0 + R_a \tag{5}$$

$$R_a = 320\pi^4 N^2 \left(\frac{\pi {r_{avg}}^2}{\lambda^2}\right)^2 \tag{6}$$

$$R_0 = \left(\frac{\mu_0 w}{2\sigma}\right)^{\frac{1}{2}} \frac{N r_{avg}}{a} \tag{7}$$

$$Q = \frac{wL}{R} \tag{8}$$

Here,
L – Spiral coil Inductance (Henrys)
R – Equivalent resistance (Ohms)
R_0 – Ohmic resistance (Ohms)
R_a – Equivalent radiation resistance (Ohms)
Q – Quality factor,
σ – Conductivity of the wire,
β – Filling rate,
a – Radius of wire and
w – Angular frequency

When two coil are coaxially coupled, its mutual inductance is calculated by

$$M = \frac{\mu_0 \pi N_1 N_2 {r_{1avg}}^2 {r_{2avg}}^2}{2\left(D^2 + {r_{1avg}}^2\right)^{1.5}} \tag{9}$$

The equation for calculating power product is as follows:

$$P_\eta = P.\eta = \frac{V^2 w^4 M^4 {R_L}^2}{Z_2 (Z_1 Z_2 + w^2 M^2)^3} \tag{10}$$

The turns of coils are calculated from wire diameter and overall structure, being aware of the role of inter-turn voltage and wire insulation level for air breakdown.

It is suggested in this work that coils have a square form. It should be noted that square function is heavily reliant on the perimeter and only slightly depending on the loop area and wire radius. As a result, the inductance of intricate forms is sometimes well approximated by a simpler shape with the same parameters.

Grover et al. investigated a number of examples for polygons with side lengths and wire radius R. Using the following formula, we can simply determine inductance.

$$L = \frac{2\mu_0 s}{\pi}\left[ln\left(\frac{s}{R}\right) - 0.52401\right] \tag{11}$$

5. The objective of the research:

The purpose of this thesis is to build, develop, and analyze a low power wireless power transfer system for storage system of hybrid electric vehicles (HEV). This system will have advantages over conventional EV charging systems, such as a more efficient system, environment friendly, convenient and flexible. In this research a circular and square topology for the wireless coil design has been designed and simulated. Design of both the coils is done using ANSYS Electronics. The simulation results suggest very interesting electrical properties. Misalignments between transmitting and receiving coils have been analyzed in all the 3 directions. Results were analyzed and frequency verses misalignments, frequency verses power, frequency verses magnetic properties readings are taken and plotted 3D images. The simulation of both (square and circular) topologies has been done using the industry standard software ANSYS Electronics and ANSYS Twinbuilder.

Hence, to achieve these objectives, the research work reported is:

1. The goal of the work is to develop hardware prototype of induction charging for storage system of HEV. Design and analysis has been done using ANSYS Electronics desktop and ANSYS Twinbuilder.

2. To analyze various electrical parameters and obtain simulation results. The results are in terms of 3D images and plots. The frequency verses efficiency plot for the selection of proper frequency to enhance the efficiency.

3. Misalignment between the two coils is analyzed for all the 3 directions (X-axis, Y-axis and Z-axis). The analysis is made using different plots and animations at different misalignments.

6. Experimental setup:

An experimental setup consists of a three phase IGBT power converter card, IGBT driver card with short-circuit protection, DSP based microcontroller, voltage Hall sensor for DC side, 3 set of current transformer (CT) and power transformer (PT) for ac side.

Circular coils have been developed with following electrical parameters. It has been derived that the efficiency at 15mm vertical separation is 95.5%.

V	f(kHz)	N	Zdist(mm)	P(W)	η(%)
230	51	20	15	3350	95.5

Table:2 working parameters.

The thesis will be organized as following:

Chapter 1: Introduction, literature review and thesis organization.

Chapter2: In this chapter, brief overview of the design of square and circular coil design presented and derived physical parameters.

Chapter3: In this chapter analytical study using ANSYS Electronics desktop and

ANSYS Twinbuilder has been done. Simulation results have been obtained and many types of plots are presented.

Chapter 4: This chapter presents comparative assessment of the simulation results (circular and square) topology of the coils and suggests suitable for the application.

Chapter 5: This chapter provides detailed description of experimental set-up of hardware.

Chapter 6: It provides discussion of the results, conclusions, and scope of future work.

Thesis ends with a complete Bibliography.

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