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REGULAR ARTICLE

Analysis of Performance Parameter of Hexagonal Coil Structure for Wireless Power Charging in Electric Vehicle

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The design characteristics of the hexagonal coil structure used as the transmitter and receiver coil pad for wireless power charging in an electric car are described in the study. Two resonant coupling coils' energy loss determines the wireless charging system's transmission power and efficiency. How many turns the transmitter and receiver coils have, as well as their size and form, impact the energy efficiency. Coupling efficiency can be increased with better designs that have coil layouts that are optimized. This paper investigates the primary factors affecting the characteristics of WPT systems: inner coil radius, coefficient of coupling, self-inductance, mutual inductance and number of turns. The intricacy of these parameters calls for finite element analysis (FEA) using the Ansys Maxwell pro-gram. The primary parameters of the WPT systems can be used to conduct an analytical calculation of the self- and mutual inductance. This coil design is validated using resonant inductive wireless charging in MATLAB tool and efficiency can be calculated. Magnetic field leakage has been studied. Here, SS compensation method and LCC-LCC topology is utilized for designing magnetic resonant coupling. The international guidelines can be ensured by the design and operation of both topologies.

Keywords: WPT, FEA, Coil design, Compensation topology, Coupling method, Self inductance, Mutual inductance, Electric vehicle.

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1. INTRODUCTION

In the modern world, environmental pollution is a crucial issue. Many nations have implemented various policies to address the issue of air pollution, most notably the growth of the new energy automotive sector. The development of the new energy vehicle industry is hindered by various problems, the method by which electric vehicles are charged. Wireless charging technology is a viable solution [1]. Wireless charging is more secure, weather-resistant, requires less space, and is handier than wired charging. Wireless power transfer (WPT) technology provides flexibility, simplicity, and safety without requiring a physical connection [2]. Researchers are increasingly interested in this technology, which is being used in electric vehicles, medicinal implants, and portable electronics, among other uses.

As the transmission distance increases, the output power and transfer efficiency drastically drop, severely restricting the advancement and use of WPT technology [3]. Advancements in magnetic coupling theory and industrial technology enable high-power and efficient wireless charging for electric vehicles. The charging system relies on the resonant coupling coil. Typical electromagnetic couplers consist of two flat plates: one that transmits electricity and is either buried or kept at ground level, and another that receives power and is mounted on the vehicle's chassis. The basic idea behind this innovative design approach is to provide the highest coefficient of coupling and horizontal offset resistance with the fewest magnetic cores.

The organization of paper is as follows: Chapter 1 describes short introduction on wireless power transfer technology; Chapter 2 describes coupling method, of which resonant coupling method is briefly explained; Chapter 3 describes coil design using Ansys Maxwell; SS compensation topology and LCC-LCC compensation topology is explained in Chapter 4 and 5 respectively. Finally, conclusion is presented in Chapter 6.

2. RESONANT COUPLING PRINCIPLE

Various types of coupling methods are utilized for WPT, of which the most common types used for electric vehicle charging are capacitive coupling, inductive coupling and magnetic resonant coupling [4]. Electric fields between two conductive plates are used in capacitive coupling to transfer energy. The

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displacement current transfers power, and the plates function as a capacitor [5]. Its advantages include being lightweight and small, but its drawbacks include being less efficient than inductive coupling and being extremely sensitive to alignment and distance. Based on the electromagnetic induction principle – the bedrock of inductive coupling – an electromagnetic field is generated when a time-varying current in the main coil induces a voltage in the secondary coil. Its benefits include easy implementation and excellent efficiency at close range transfer [6]. Its disadvantage is that as coil distance increases, performance decreases and coil misalignment significantly lowers efficiency [7]. Magnetic resonance coupling is the transfer of energy between resonant devices tuned to the same frequency using magnetic fields [8]. Its advantages include long-range capabilities and the capacity to power many devices concurrently. Its disadvantages include increased complexity and cost [9].

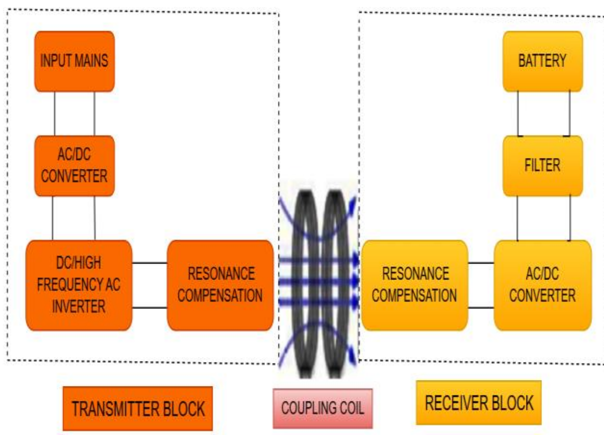


Fig. 1 – Block diagram of magnetic resonant coupling method used in WPT

Out of these three methods, magnetic resonance coupling is the best method of power transfer in WPT as inductor and capacitor can be made to oscillate at resonant frequency which will induce higher power to transfer between transmitter and receiver resulting in higher efficiency [10]. Fig. 1 shows the block diagram of magnetic resonant coupling method.

3. COIL DESIGN

According to [11], circular, rectangular and hexagonal coil for wireless power transfer (WPT) has been analyzed. It shows that hexagonal coil is the most efficient option in terms of coefficient of coupling, cost and weight, and misalignment tolerance. In this paper, we have carried forward the hexagonal coil design and implemented in WPT for EV charging applications.

We have used hexagonal coil structure with 20 turns and coil is designed using Ansys Maxwell software. The various parameters for hexagonal coil structure is shown in Table 1.

Table 1 – Hexagonal coil model characteristics

Specifications	Dimensions
Polygon segments	6
Radius of Polygon	5 mm
Helix radius start	10 mm
Change of Radius per turn	10.05 mm
Pitch	0 mm
No. of turns	20

Fig. 2 shows the hexagonal coil design for transmitter and receiver coil placed in alignment to each other. Simulation validation and analysis is done for coil distance from 50 mm to 300 mm and we get self-inductance and mutual inductance value which is shown in Table 2. Table 2 shows that as distance rises, mutual inductance decreases. No matter how far apart the coils are, their self-inductance is constant.

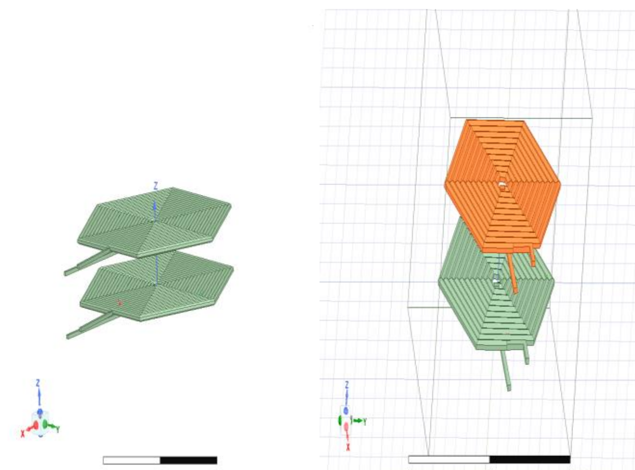


Fig. 2 – Hexagonal coil design for transmitter and receiver coil

By adjusting the longitudinal distance between the coils, the coupling coefficient of hexagonal coil is examined in the electromagnetic modeling program Maxwell. The coupling coefficient is ascertained by doing this. During this study, the sending and receiving coils' centers line up. Table 3 displays the experiment's findings. By analyzing coil distance from 20 mm, we can see that coefficient of coupling decreases from 0.2822 to 0.0048 for 200 mm coil distance.

Table 2 – Self and Mutual inductance of coil

Distance (mm)	No of Turns-20	
	Self-Inductance (μH)	Mutual Inductance (μH)
50	39.3	18.94
100	39.2	9.812
150	39.2	5.011
200	39.3	2.717
250	39.3	1.500
300	39.1	0.840

Table 3 – Coefficient of coupling for hexagonal coil

Distance (mm)	Hexagonal Coil	
	Rx_in-Rx_in	Rx_in-Tx_in
20	1	0.2822
40	1	0.2511
60	1	0.1023
80	1	0.0832
100	1	0.0657
120	1	0.0345
140	1	0.018
160	1	0.009
180	1	0.006
200	1	0.0048

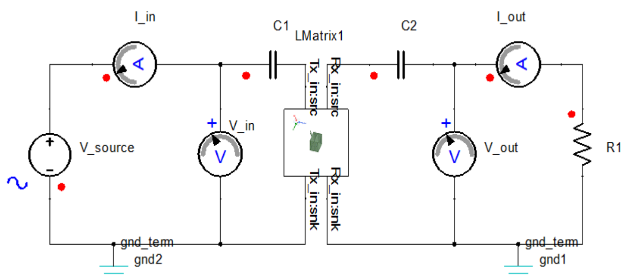


Fig. 3 – SS topology for coil design using twinbuilder

The proposed coil design is exported to Ansys Twinbuilder software as shown in Figure 3. Using Ansys Twinbuilder, we can tune capacitor to get the resonant frequency. This is done by keeping inductance value constant. Hexagonal coil self-inductance value is simulated to be approximately 40 μH. By tuning capacitor to 89.7 nF, we get the maximum efficiency (99.84%). Fig. 4 shows frequency vs efficiency waveform.

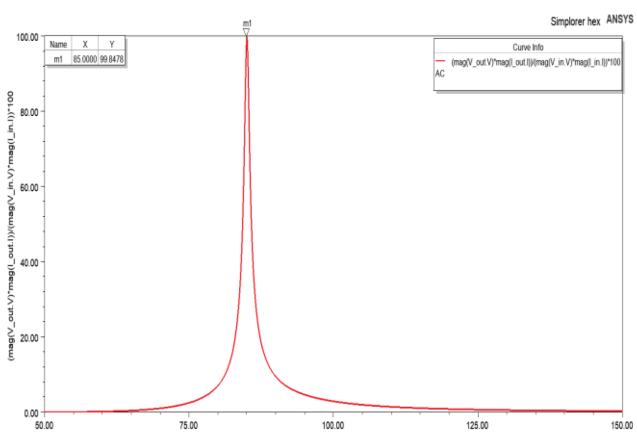


Fig. 4 – Efficiency vs frequency graph using twinbuilder

The inductor and capacitor together forms a compensation tank. In this paper, we have designed series – series (SS) compensation and LCC-LCC compensation topology.

4. SS COMPENSATION TOPOLOGY

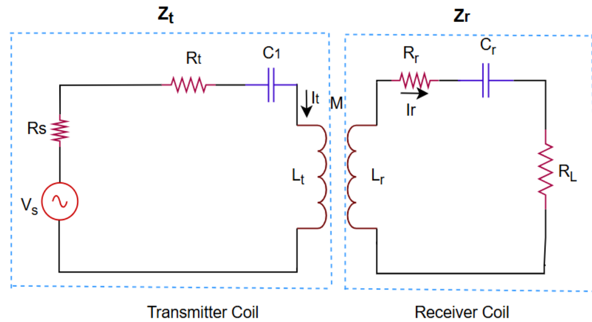


Fig. 5 – Equivalent circuit diagram of SS topology

Fig. 5 shows the equivalent circuit diagram of series-series compensation topology [12]. It consists of a capacitor, C_t connected in series with the transmitter coil (L_t). Receiving side capacitor, C_r is connected in series with the receiving side coil (L_r) [13]. All these parameters are designed using Matlab simulation. Table 4 shows various simulation parameters used in SS topology.

Table 4 – Various simulation parameter and their values

Symbol	Parameter	Value
V_source	Input Voltage	230 V
f_0	Resonance Frequency	85 kHz
L_1	Primary side Inductance	40 μH
L_2	Secondary side Inductance	40 μH
M	Mutual Inductance	28 μH
R_1	Primary side Resistance	1 Ω
R_2	Secondary side Resistance	1 Ω
C_1	Primary side Capacitance	89.7 nF
C_2	Secondary side Capacitance	89.7 nF
R_{load}	Load Resistance	10 Ω

Fig. 6 shows the Matlab simulation of SS compensation topology. The compensating capacitors are linked in series with the transmitter and receiving side. Fig. 7 shows of waveform of input and output voltage and current with respect to time.

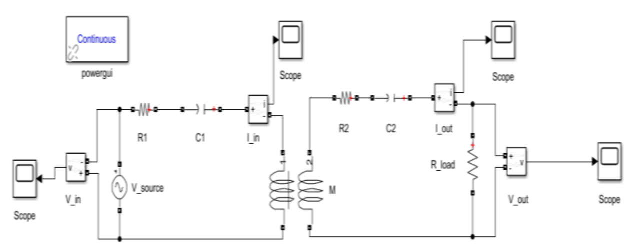
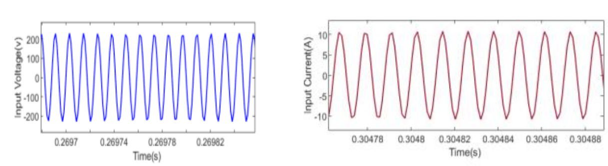


Fig. 6 – Matlab simulation of SS topology



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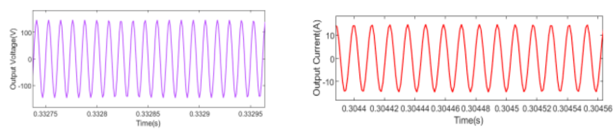


c d

Fig. 7 – Current and voltage waveform for SS WPT: (a) Input voltage; (b) Input current; (c) Output voltage; (d) Output current

From the above waveform, we can note that input volt-age is set as 230 V, input current is found to be 10 A. Output voltage is 150 V and output current is 13A. So the input power is 2.3 kW and output power is 1.95 kW. Efficiency is calculated by dividing output power to the input power multiplied by 100. So the overall efficiency is found to be 84.78 %.

5. LCC-LCC COMPENSATION TOPOLOGY

Fig. 8 shows the equivalent circuit diagram of LCC-LCC compensation technique [14]. Here two capacitors are connected in series and parallel with the inductor coil in both the transmitter and receiver coil [15].

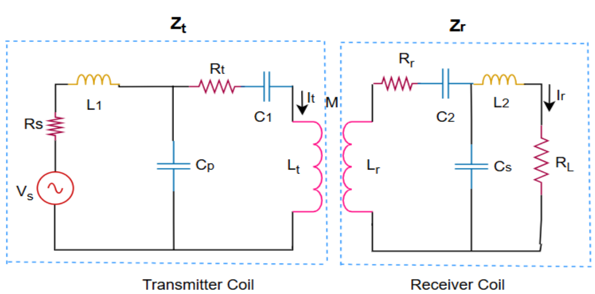


Fig. 8 – Equivalent circuit diagram of LCC-LCC topology

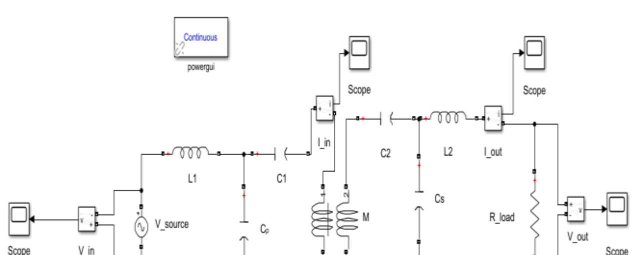
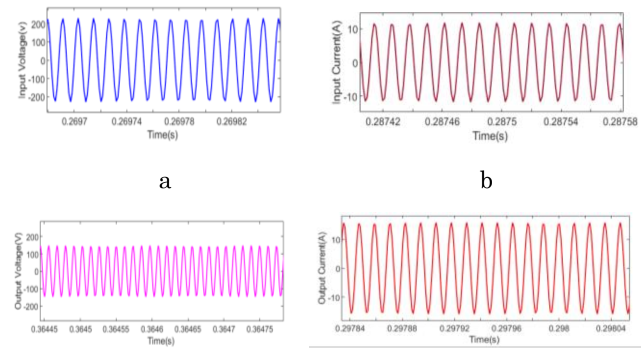


Fig. 9 – Matlab simulation of LCC-LCC topology

Fig. 9 shows the Matlab simulation of LCC-LCC compensation topology and figure 10 shows the wave-form of input and output voltage and current with respect to time.



a b c d

Fig. 10 – Current and voltage waveform for LCC-LCC WPT: (a) Input voltage; (b) Input current; (c) Output voltage; (d) Output current

Table 5 – Efficiency table for two compensation method

Compensation Method	Efficiency
SS	84.78 %
LCC-LCC	93.59 %

Simulation result shows that input voltage and current is 148 V and 16 A respectively. So the input power is 2.53 kW and output power is 2.36 kW. The overall efficiency is 93.59 %. Table 5 shows the comparison of two compensation method in terms of efficiency.

6. CONCLUSIONS

This work proposes a novel form of coil with a hex-agonal outer perimeter primarily designing and optimizing the structure of the magnetic coupling coil in the resonator of electric vehicle wireless charging. LCC-LCC compensation topology holds higher efficiency as compared to SS topology. Resonance reduces switching losses, minimize reactive power enhancing high power transfer scenarios. Also, LCC-LCC compensation per-forms reasonably well under slight coil misalignments.

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Аналіз параметрів продуктивності шестикутної котушкової структури для бездротової зарядки електромобіля

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Кафедра електротехніки та електроніки, Інженерно-технологічний коледж, Інститут науки й технологій SRM, Каттанкулатур, Ченгалпатту, Тамілнад, Індія

У цій статті описано конструктивні характеристики шестикутної котушкової структури, яка використовується як котушка-передавач і котушка-приймач для бездротової зарядки електромобілів (WPT – Wireless Power Transfer). Втрати енергії у системі резонансного зв'язаного передавання енергії визначають ефективність передачі потужності. На неї значно впливають такі параметри: кількість витків, розмір та форма котушок, внутрішній радіус, коефіцієнт зв'язку, власна індуктивність, взаємна індуктивність. Оптимізація геометрії котушок дозволяє підвищити коефіцієнт зв'язку та, відповідно, зменшити втрати потужності Для моделювання електромагнітних властивостей застосовано метод скінченних елементів (FEA) в Ansys Maxwell. Проведено аналітичні розрахунки власної та взаємної індуктивності. Дизайн перевірено в MATLAB з використанням резонансної індуктивної бездротової зарядки. Досліджено витік магнітного поля, Застосовано компенсацію SS і топологію LCC-LCC для реалізації магнітного резонансного зв'язку. Проєкт відповідає міжнародним нормам електромагнітної безпеки та функціональності.

Ключові слова: Бездротова передача енергії (WPT), Скінченно-елементний аналіз (FEA), Конструкція котушки, Компенсаційна топологія, Метод зв'язку, Власна індуктивність, Взаємна індуктивність, Електромобіль.