Design of U and I Ferrite Core On Dynamic Wirelesss Charging for Electric Vehicle

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***Abstract*— This study provides an approach investigation of U and I ferrite core geometrics to improve the power efficiency for Electric Vehicle (EV) inductive wireless charging in dynamic mode. Dynamic wireless charging (DWC) enables recharging of battery pad during the vehicle is on the road. Hence, the design of battery pad must deal with two main factor that led to power leakage such air gap and misalignment. Using ferrite magnetic core, it improves the power transferred by reduce the leakage magnetic radiation between primary and secondary side. Different conditions are investigated on U and I core. The first and second condition is U or I core only at primary side and secondary U or I core only at the secondary side. The last condition is both at primary and secondary side of U or I ferrite core. The purpose of this project is to design a prototype of EV thru several method, design proposed, circuit simulation, pair simulation and prototype development. NI Multisim are used to simulate circuit of WPT for operation validity.**

Keywords— Dynamic wireless charging, inductive wireless charging, electric vehicle, magnetic flux density, air gap and misalignment.

I. INTRODUCTION

Electric Vehicles (EV), which are not a new concept, were developed in the mid-19th century. However, they became obsolete throughout almost entirely the 20th century mainly because of their limited driving range and high cost as compared to gasoline powered vehicles. The number of vehicles on the road is getting increase and the total number is expected to reach the level of 2.5 billion in 2050 [1].

With regards to the future transport significant, electric vehicles (EV) are considered as the likely replacement of internal combustion engine driven vehicles, especially reduce the Carbon Dioxide (CO_2) emission. Electric vehicle can possibly lessen carbon discharges, air pollution and reliance on imported oil. Many researchers realize the significant of EV on the future since EV is not widely used in entire world. Fig. 1 shows the number of CO_2 gas emission in Malaysia between year 2000 until 2018 for transportation sector. Throughout this period, CO_2 gas emissions has doubled to 65 MtCo2e. In 2018, over 85% of CO_2 gas emissions were attributed to road transport, of which cars and motorcycles were responsible for roughly 70% [2][3].

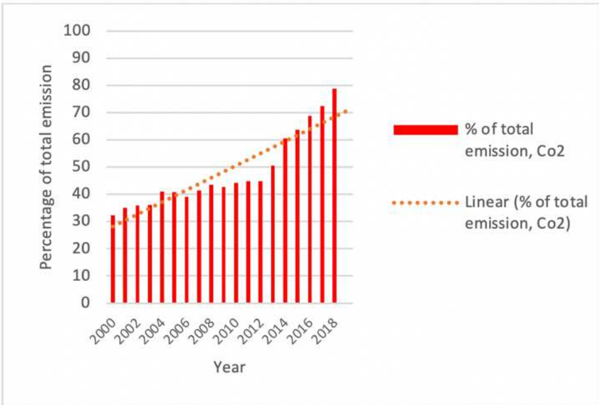

Fig. 1 Total Transportation Emissions in Malaysia [4]

Due to increase of CO_2 emission from transportation sector, the government agency such as Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC) has agreed to change combustion engine car to electric car as this can reduce the usage of fossil fuel and release of CO_2 emission to the environment. In July 2018, Malaysian Green Technology Corporation known as GreenTech Malaysia has proposed a national car project to the Ministry. GreenTech Malaysia CEO, Dr Mohd Azman Zainul Abidin said that the current progress of the national car proposal is inclining more towards the electric car development in Malaysia. This effort is also supported by MESTECC and other relevant government authorities that agree EV is the only clean energy sources that could power

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eco-friendly vehicles [5]. According to Mohd Azman the new government is very concerned about the environment and climate change, which gives a concrete reason to implement EV in Malaysia.

Despite of the advantages of EV, it also came with some problems regarding of charging system [6][7]. Nowadays, Static Wireless Charging System (SWCS) has been applied widely as new technology transportations. SWCS have been used in plug-in electric vehicles in stationary application such as car parks area, garages or at traffic signals [8]. However, SWCS can only be utilised when the car is at stationary modes. Moreover, SWCS have limitations and challenges in term of Electromagnetic Compatibility (EMC) issues, limited power transfer, shorter range and efficiency [9].

Wireless charging is preferred to be used as the system is more convenient [10]. Wireless charging is the contactless connection between grid and vehicle which can be established in a few seconds. Static wireless charging allows recharging process to take place once the vehicles is located at the above charging plate and must be in static. Whilst, dynamic wireless charging is better for recharging process where recharging the battery pack is done in motion [11][12][13]. However, the biggest elements that must be tolerated with the dynamic wireless charging system is the airgap and misalignment [14]. Even though many studies show the effectiveness of wireless pad design using ferrite core, they rarely proposed an effective method to solve the problems by varying the geometric shape of ferrite shape. Therefore, this project will propose a few combinations of ferrite core shapes on Wireless Power Transfer (WPT) system on EV. This works is divided into two technical tests. The first test will be on simulation analysis using NI Multisim software. The second test is on experimental work. The design that improves the coil coupling is the main contribution of this study. Four methods introduce in WPT, Inductive Power Transfer (IPT), Capacitive Wireless Transfer (CWT), Magnetic Gear Wireless Power Transfer (MGWPT) and Resonant Inductive Power Transfer (RIPT) [15].

In this paper, Resonant Inductive Power Transfer (RIPT) made up from two copper coil that acts as transmitter and receiver are proposed. The coil place with each other to allow power to transmit through air is known as wireless method. The receiver circuit is connected with the battery storage to charge the EV battery system. Fig. 2 shows the schematic diagram of dynamic wireless charging system. AC power supply supplies the voltage power through transmitter coil. In primary side, magnetic field is produced while the current will induce at secondary side caused magnetic field generated at the receiver side. AC signal will convert to DC signal to charging load or EV battery. The process is known as inductive resonance coupling method in which resonance frequency at both primary and secondary side is same. The resonance frequency used in this study is 26 kHz. In Section II of this paper will be discussed about the methodology while Section III will evaluate the simulation and experiment result, Section IV will conclude the paper.

II. METHODOLOGY

In this section, the technique and methodology to design the most efficient charging pad for EV is explained. There are few designs of the magnetic power transfer system in the literature [16][17] that will be interpreted in this section too. Three main process in this project was highlighted so that coincident with the research objectives. The steps are coil parameters, core shape, experiment settings and evaluation. In the first part of the research, the objective one which is to achieve maximum power transfer by reducing flux leakage in the system. The last steps by conducting an experiment to obtain the test result from the prototype. From the simulation and experiment, the results obtained from both analyses compared to finalize which combination of pair will have greater power transfer. Two main parts will be conducted to study the performance of U and I ferrite core. The first part is running NI Multisim software on parameters calculated using equation that has been study from [14][16][17]. This is crucial to the research because in this part the validity of parameter value is approved before used in the experiment later. There will be two cases in this study which is ideal case and overall system condition. The final result using NI Multisim is power efficiency in overall cases that will be compared with experimental test. Meanwhile, this study proposed six design of combination ferrite core in the wireless power transfer system. These six designs of ferrite core have been set up for the experiment test. Table 1 shows the proposed designs of U and I ferrite core in this study.

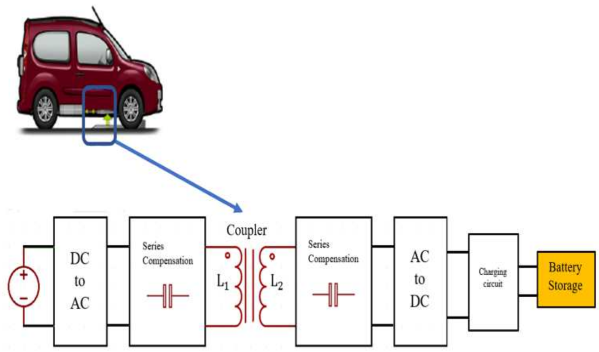

Fig. 2 Schematic diagram of dynamic WCS [15]

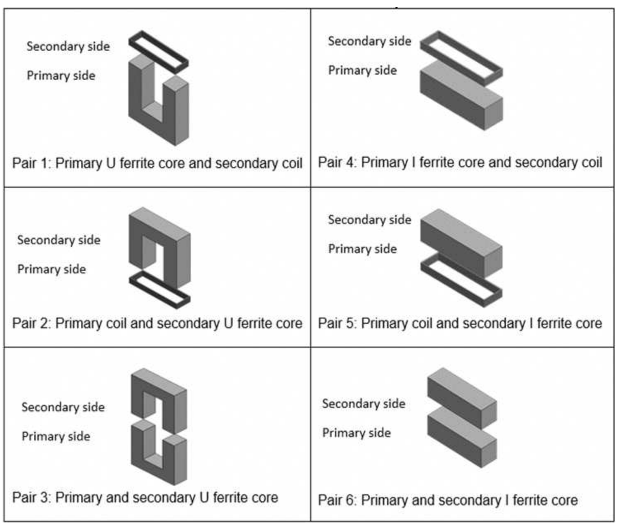

Fig. 3 Six Pairs of Ferrite Core with Variety of Conditions

A. Calculations on Parameters Used

Using NI Multisim software, two cases of wireless power transfer will be simulated and running thru the software. For the first case is called ideal case. In this case, there are no internal and external resistance in the system. The second condition is overall system in which the additional components that used in the experiment is connected too in construction using NI Multisim. Here, the power efficiency obtained is used to compare with the experiment test. Fig. 4 shows the general flowchart methodology in this research. The comparison of power efficiency between using NI Multisim and experimental will be discussed. Further procedure of each test using NI Multisim will be explained later.

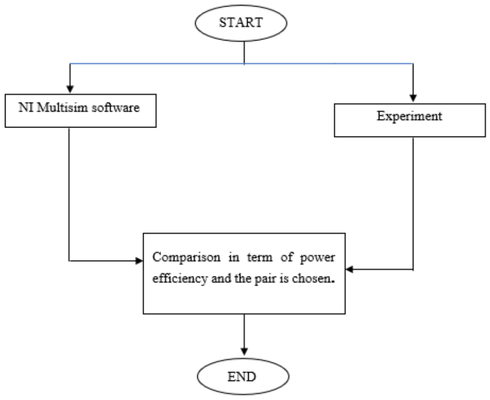

Fig. 4 Overall Flowchart of the Research Wireless Charging System

For the first case, a study of ideal condition will have few basic parameters in the circuit which are primary voltage (*Vp*), primary resistance (*Rp*), primary capacitor (*Cp*) and primary inductance (*Lp*) at primary side. In the meantime, at secondary side the basic components are secondary resistance (*Rs*), secondary capacitance (*Cs*) and secondary inductance (*Ls*) and load resistance (*Ls*). Fig. 5 shows the general circuit of wireless power transfer.

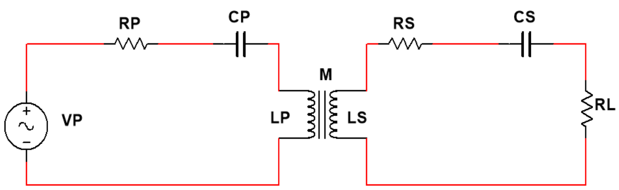

Fig. 5 Wireless Charging Representation in Schematic Diagram

The parameters need to be calculated from the schematic circuit as shown in figure above. All parameters value needs to be calculated to be used in constructing the circuit for both ideal and overall system condition. Table I listed the calculated parameters to be used in NI Multisim software [14].

The validity of the parameters can be approved if the running simulation of the ideal case obtained have the same power at primary and secondary side, since there is no internal and external resistance occurs. The current and voltage value will be as a result from running NI Multisim software. Power calculation can be calculated at both primary and secondary side using Equation (1) below.

$$P = V*I \qquad (1)$$

where;

P is the power of primary/ secondary side (Watts)

V is the voltage at primary/ secondary side (V)

I is the current at primary/ secondary side (A)

TABLE I. CALCULATED PARAMETERS FOR NI MULTISIM SIMULATION

Parameters	***Values***
$V_{p,rms}$	12 V
$V_{s,rms}$	5 V
$I_{p,rms}$	1.39 A
$I_{s,rms}$	3.33 A
R_L	1.5 Ω
L_p	330.7 MH
L_s	36.7 MH
M	22.0 MH
C_p	113.3 NF
C_s	1022.4 NF

Fig. 6 and Fig. 7 shows the constructed circuit for ideal and overall condition in the simulation. As can be seen from Fig. 6, the ideal condition here assumed that the circuit work perfectly without any disturbance. The resistance value for primary and secondary is assumed to be 0 **Ω**.

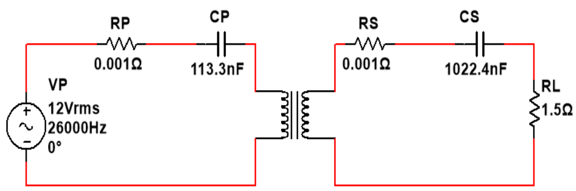

Fig. 6 Schematic Diagram of Ideal Case for Wireless Power transfer in NI Multisim.

While, for the second case is overall condition in which additional components are connected to the circuit. The connected components for the second condition will be used to construct the hardware setup. From Fig. 6, the connected of circuit become more complex than the previous ideal circuit system. Therefore, it is expected there will be disturbance in the system.

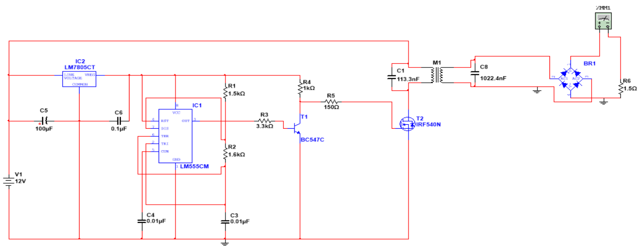

Fig. 7. Schematic Diagram of Overall Condition for Wireless Power transfer in NI Multisim.

To summarize, two cases are being analyzed using NI Multisim software on wireless power transfer. This project aims to produce 16.7 W at the secondary side. Hence, work calculation is completed first before proceeding to ideal case then overall condition. Calculation has been done and listed as shown in Table I. Next, the parameters value is test in ideal condition where the efficiency here should be 100% of power transfer because there is no internal resistance. After proven the validity of calculated parameters, the overall condition is being test and power efficiency at secondary side is obtained. Fig. 8 shows the flowchart of the simulation system using NI Multisim software.

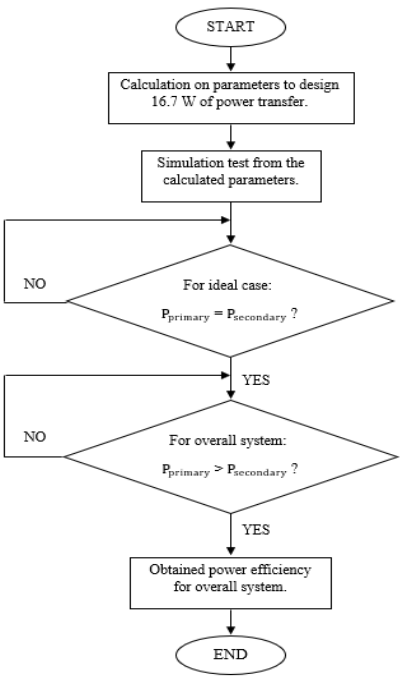

Fig. 8. Flowchart of first test on WPT system using NI Multisim.

III. RESULT AND DISCUSSION

In this section results obtained from both in simulation and experiment are discussed. In simulation part, two condition are test on wireless power transfer system. NI Multisim software is used is running the simulation for both conditions. This section verified the results for both conditions and discuss the experimental result that have been obtained.

A. *Simulation using NI Multisim Software*

Define Fig. 9 is the display output in NI Multisim software for ideal case. 12 V of rms input voltage as source to the circuit and resonance frequency of 26 kHz [18]. After running the simulation, the ammeter and voltmeter at primary and secondary side gives different reading. However, since this is the ideal case, the efficiency is 100% of power are transferred. After calculating the power efficiency for both calculated and simulated, the value obtained is listed in Table II.

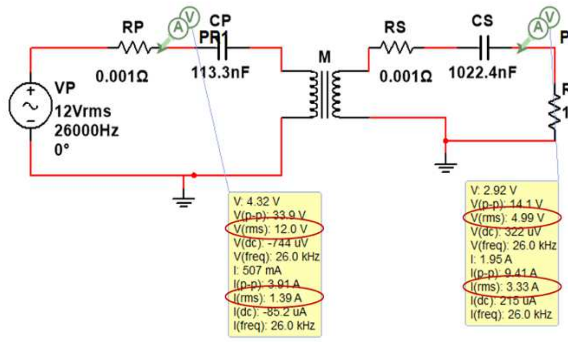

Fig. 9. Simulation Results for ideal Condition in NI Multisim Software.

TABLE II. RESULT OF IDEAL CASE IN NI MULTISIM

	Calculated	**Simulated**
Primary voltage (rms)	12 V	12 V
Secondary voltage (rms)	5 V	4.99 V
Primary current (rms)	1.39 A	1.39 A
Secondary current (rms)	3.33 A	3.33A
Power transmitted	16.7 W	16.68 W
Power received	16.7 W	16.62 W
Power efficiency, η (%)	100 %	99.6 %

The efficiency of power transfer for both calculated and simulated can be obtained using Equation (2) below.

$$\text{Efficiency, } \eta = \frac{P_{received}}{P_{transmitted}} \text{ x } 100\ \% \qquad (2)$$

Calculated Efficiency, **η** = (16.7/16.7) x 100 % = 100%

Simulated Efficiency, **η** = (16.62/16.68) x 100 % = 99.6%

From Table II, the value of error calculated is 0.4%. Therefore, all the parameters from the calculation work can be used in overall case. The same value for inductance (*Lp, Ls*) capacitor (*Cp, Cs*) and load resistor (*RL*) will be applied in the experimental set up to verify the wireless power transfer circuit. In Fig. 10 shows the simulation result of an overall system that was studied in this project.

The circuit has been directly supplied by 12 V DC of input voltage to the circuit. Since AC signal form should be transferred, a timer 555 is used to convert from DC signal to AC signal. To activate the timer 555, it requires 5 V input voltage. The signal form after the timer is AC which a signal form that can be transferred to the secondary side. Power received now in AC signal. The bridge rectifier as shown in the Fig.9 is used to convert from AC signal back to DC signal. Then the power efficiency can be calculated.

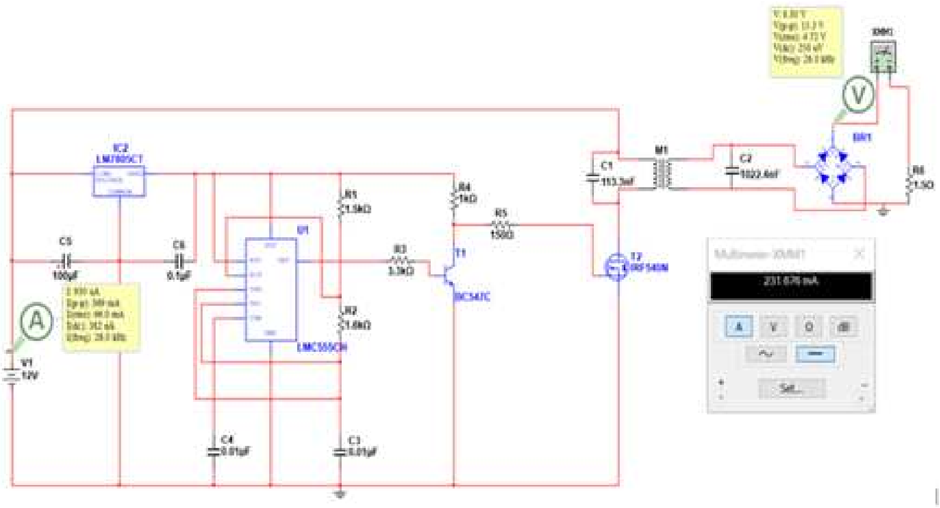

Fig. 10. Simulation Result of an Overall System in NI Multisim Software.

Next is to calculate the power efficiency where the value of power transferred and power received must be known first. As the input voltage is 12 V DC, the current input DC is measured by attached a current probe at the wire. The current input DC measured is 96 mA. Meanwhile, to measured DC voltage and DC current at secondary side, a voltage probe and multimeter is attached to the secondary circuit as shown in Fig. 10 above. The measure voltage and current in secondary side is 4.72 V and 231.676 mA. The resonance frequency in both at transmitter and receiver side is 26.0 kHz. The power transferred and power received are calculated using equation 3.9. Then, the power efficiency can be calculated as below:

$P_{transferred} = V_{PDC} \times I_{PDC} = 12V \times 96mA = 1.152W$

$P_{delivered} = V_{SDC} \times I_{SDC} = 4.72V \times 231.676mA = 1.0935W$

$P_{efficiency} = \frac{P_{delivered}}{P_{transmitted}} \times 100\% = 1.0935/1.152 \times 100\% = 94.9\%$

The power efficiency for overall case in this study is 94.9 %. Note that the minimum requirement efficiency for wireless charging is 85%. Therefore, the parameters used is valid to be used for experimental test.

IV. CONCLUSION

In this paper, a simulation and prototype of EV charging system wireless power transfer using inductive coupling principle was developed. The running simulation and performance of the prototype was also observed and measured. The simulation in NI Multisim for ideal case has proven that the equation used to calculate the parameter is valid since the error between calculation and simulation is only 0.4%. Meanwhile for overall system is satisfied with 94.9 % of power efficiency. From the calculation analysis, ferrite pair of U shape delivered more power transfer since the geometry shape of U ferrite core reduce the leakage induction.

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REFERENCES

[1] A. Ahmad, M. S. Alam, S. Member, and R. Chabaan, "A Comprehensive Review of Wireless Charging Technologies for Electric Vehicles," *IEEE Trans. Transp. Electrif.*, vol. 4, no. 1, pp. 38–63, 2018.

[2] H. G. Briggs and H. K. Leong, "Malaysia Stocktaking Report on Sustainable Transport and Climate Change - Data, Policy, and Monitoring," p. 111, 2016.

[3] A. Ghadimzadeh, A. Ahmad Makmom, M. Kato Hosea, N. Asgari, R. Shamsipour, and T. Sheikhy Narany, "Review on CO 2 Emission from Transportation Sector in Malaysia," *IOSR J. Environ. Sci.*, vol. 9, no. 5, pp. 61–70, 2015.

[4] D. Joshi, "Electric Vehicles in Malaysia ? Hold Your Horsepower !," 2018.

[5] M. . Paridah, A. Moradbak, A. . Mohamed, F. abdulwahab taiwo Owolabi, M. Asniza, and S. H. . Abdul Khalid, "We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %," *Intech*, vol. i, no. tourism, p. 13, 2016.

[6] F. Lu, S. Member, H. Zhang, and S. Member, "Output Power Pulsation for Electric Vehicles," *IEEE Trans. Ind. Electron.*, vol. 63, no. 10, pp. 6580–6590, 2016.

[7] X. Zhang, Z. Yuan, Q. Yang, Y. Li, J. Zhu, and Y. Li, "Coil Design and Efficiency Analysis for Dynamic Wireless Charging System for Electric Vehicles," *IEEE Trans. Magn.*, vol. 52, no. 7, pp. 2–5, 2016.

[8] K. A. Kalwar, M. Aamir, and S. Mekhilef, "A design method for developing a high misalignment tolerant wireless charging system for electric vehicles," *Meas. J. Int. Meas. Confed.*, vol. 118, no. December 2017, pp. 237–245, 2018.

[9] K. Aditya and S. S. Williamson, "Design guidelines to avoid bifurcation in a series-series compensated inductive power transfer system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 3973–3982, 2019.

[10] T. Maruyama, "Education for the college student through study of wireless power transmission (WPT)," *2017 IEEE Int. Conf. Comput. Electromagn. ICCEM 2017*, pp. 89–91, 2017.

[11] R. Shadid, S. Noghanian, and A. Nejadpak, "A Literature Survey of Wireless Power Transfer," *2016 IEEE Int. Conf. Electro Inf. Technol.*, pp. 782–787, 2016.

[12] S. Maindad, "Global Dynamic Wireless EV Charging System Market 2019 | Newest Industry Data, Future Trends And Forecast 2025," 2019. [Online]. Available: http://techdosedaily.com/2019/02/18/global-dynamic-wireless-ev-charging-system-market-2019-newest-industry-data-future-trends-and-forecast-2025/.

[13] M. Debbou and F. Colet, "Inductive Wireless Power Transfer for Electric Vehicle Dynamic Charging," *2016 IEEE PELS Work. Emerg. Technol. Wirel. Power Transf.*, pp. 118–122, 2016.

[14] K. Aditya, V. K. Sood, L. Fellow, S. S. Williamson, and S. Member, "Magnetic Characterization of Unsymmetrical Coil Pairs Using Archimedean Spirals for Wider Misalignment Tolerance in IPT Systems," *IEEE Trans. Transp. Electrif.*, vol. 3, no. 2, pp. 454–463, 2017.

[15] C. Panchal, S. Stegen, and J. Lu, "Review of static and dynamic wireless electric vehicle charging system," *Eng. Sci. Technol. an Int. J.*, vol. 21, no. 5, pp. 922–937, 2018.

[16] N. N. Nanda, S. H. Yusoff, S. F. Toha, N. F. Hasbullah, and A. S. Roszaidie, "A brief review: Basic coil designs for inductive power transfer," Indones. J. Electr. Eng. Comput. Sci., vol. 20, no. 3, pp. 1703–1716, 2020, doi: 10.11591/ijeecs.v20.i3.pp1703-1716.

[17] S. A. Zaini, S. H. Yusoff, A. A. Abdullah, S. Khan, F. A. Rahman, and N. N. Nanda, "Investigation of magnetic properties for different coil sizes of dynamic wireless charging pads for electric vehicles (EV)," *IIUM Eng. J.*, vol. 21, no. 1, pp. 23–32, 2020, doi: 10.31436/iiumej.v21i1.1108.

[18] M. Mohammad and S. Choi, "Optimization of Ferrite Core to Reduce the Core Loss in Double-D Pad of Wireless Charging System for Electric Vehicles," pp. 1350–1356, 2018.

[19] L. Strauch, M. Pavlin, and V. Boštjan, "Optimization , design , and modeling of ferrite core geometry for inductive wireless power transfer," vol. 49, pp. 145–155, 2015.

[20] M. A. Z. Abidin, W. I. Ibrahim, and M. S. Jadin, "Design of inductive power transfer (IPT) for low-power application," *ARPN J. Eng. Appl. Sci.*, vol. 10, no. 21, pp. 9807–9812, 2015.

[21] G. Sultana, D. T.R, P. Bhushan, M. Azeem, and S. G.N, "Design and Implementation of Wireless Power Transfer Charging System on Miniature Model," *Int. J. Electr. Electron. Eng.*, vol. 3, no. 4, pp. 45–49, 2016.

[22] A. F. Abdul Aziz, N. A. Binti Anuar, M. Z. Zainol, and M. F. Romlie, "Effect of Ferromagnetic Material in Circular Magnetic Structure for Electric Vehicle Wireless Power Transfer," *Int. Conf. Intell. Adv. Syst. ICIAS 2018*, pp. 1–6, 2018.

[23] J. Lu, S. Stegen, and N. Campus, "Investigation of Magnetic Flux Distribution of EV Wireless Charging Systems," pp. 5–8, 2016.

[24] V. K. Pathipati, N. A. Azeez, S. S. Williamson, N. Dohmeier, and C. Botting, "Performance Analysis of a High-efficiency Multi-winding Wireless EV Charging System Using U-U and U-I Core Geometries," *2016 IEEE Transp. Electrif. Conf. Expo*, pp. 1–8, 2016.

[25] J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.

[26] I. S. Jacobs and C. P. Bean, "Fine particles, thin films and exchange anisotropy," in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.

[27] K. Elissa, "Title of paper if known," unpublished.

[28] R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[29] Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, "Electron spectroscopy studies on magneto-optical media and plastic substrate interface," IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].

[30] M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.