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Optimizing wireless power transfer efficiency: an empirical analysis of switching frequency variations

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ABSTRACT

This study explores the impact of switching frequency variations on wireless power transfer (WPT) system efficiency through rigorous experimental analysis. Our tests reveal that lower switching frequencies can enhance system efficiency by up to 30% by reducing resistive losses. These findings establish an optimal frequency range that significantly improves performance. The research integrates empirical data with theoretical models to elucidate electromagnetic principles like the skin effect and its impact on frequency-dependent behaviors. This comprehensive approach not only confirms the experimental methodology but also provides robust numerical evidence, making a novel contribution to the field. The results have significant implications for renewable energy and sustainable technology development, suggesting practical applications in designing energy efficient WPT systems for consumer electronics and electric vehicle charging. This paper quantitatively defines the efficiency benefits of specific frequency ranges, advancing the deployment of wireless power technologies.

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1. INTRODUCTION

Wireless power transfer (WPT) technology has garnered significant attention due to its potential to provide convenient and safe energy transfer without physical connections. The technology is underpinned by principles such as electromagnetic induction and resonant coupling, which involve the transmission and reception of power through oscillating magnetic fields. The efficiency of these systems is fundamental, as it determines the viability and sustainability of WPT in practical applications, including electric vehicle charging and consumer electronics [1]-[12].

The concept of WPT can be traced back to the pioneering work of Nikola Tesla, who, following the validation of Maxwell's electromagnetic theory by Hertz, envisioned the global transmission of electrical power without wires. Although Tesla's initial efforts, such as the Wardenclyffe tower project, were not fully realized, they laid the groundwork for future explorations in WPT. Later, the demonstration of microwave-powered helicopter flight by Brown [13] showed the potential of WPT for untethered mobility, albeit with limitations that curtailed its development at the time [13]-[15].

The significant leap in WPT technology occurred in 2007 when MIT researchers successfully powered a 60 W light bulb over a distance of more than 2 meters, showcasing the potential of resonant coupling [16]. This resurgence of interest in WPT brought forward the challenges of efficiency, particularly in relation to the system's switching frequency, which influences numerous parameters such as switching loss, coil dimensions, and the number of turns in the coils. The optimization of these parameters is crucial for the development of cost-effective WPT systems [17]-[19].

The variation of switching frequency is a critical aspect of WPT system design. Lower switching frequencies have been associated with higher efficiency due to reduced losses in switching components. However, high-frequency operation can lead to increased conduction losses and electromagnetic interference (EMI), which can detract from system performance. Recent studies have focused on finding an optimal balance, with innovations such as frequency reconfigurable metamaterials enhancing efficiency and safety in WPT systems [20].

Contemporary research in WPT has introduced advanced techniques for efficiency optimization. For instance, researchers have developed methods to reduce switching frequency while maintaining high-frequency resonance in the system, thus achieving efficient power transfer with lower losses. The integration of novel materials and metamaterials has also been explored to mitigate losses and improve efficiency. Additionally, there has been progress in dynamic power transfer control, allowing WPT systems to adapt to varying device requirements and environmental conditions [19], [20].

The evolution of WPT technology continues to be driven by the need for more efficient, safe, and practical energy transfer methods. Ongoing research is addressing the challenges associated with switching frequency and system design. The insights gained from this body of work are instrumental in paving the way toward more sustainable and convenient wireless energy solutions. Future research should focus on practical demonstrations and the integration of WPT systems in real-world applications, considering factors such as alignment, environmental influences, and regulatory compliance [19], [20].

WPT facilitates the wireless transmission of electricity to direct current (DC) loads by converting DC voltage to AC through a high-frequency full-bridge inverter. This AC is channeled to a transmitter coil with a compensating circuit to enhance power transfer efficiency. The magnetic field generated by the transmitter coil is captured by the receiver coil, which, through resonant coupling when both coils resonate at the same frequency, enables efficient energy transmission. The energy is then converted back to DC by a high-frequency full-wave diode bridge rectifier to power the DC load. WPT operates on the principles of electromagnetic induction and resonant coupling, allowing for energy transfer without direct contact. The system comprises a power generation subsystem, including a high-frequency inverter and transmitter coil, and a power reception subsystem, consisting of a receiving coil and an AC-DC converter, to maintain a pure DC output despite an air gap between components, as illustrated in Figure 1 [19], [20].

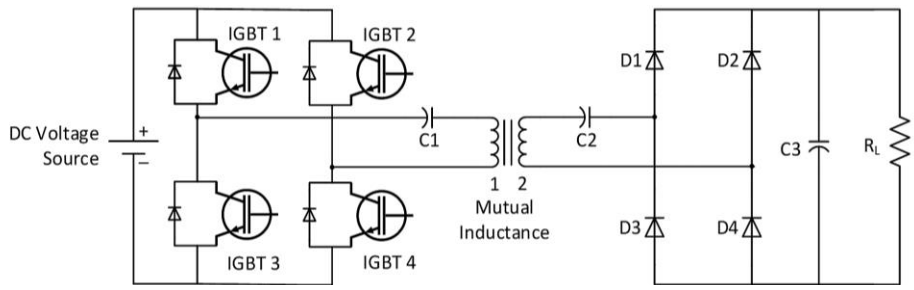

Figure 1. Typical WPT schematic diagram

Magnetically coupled resonance WPT technology, akin to inductive wireless power transfer (IWPT), operates on the air transformer principle, where the operating resonance frequency of the coils is of critical importance. This method utilizes frequencies in the range of several to tens of megahertz, allowing energy transfer over several meters regardless of environmental conditions. A significant advantage of this technology is the non-reliance on the alignment of the transmitter and receiver, enabling energy transfer as soon as the receiver enters the transmitter's range. However, its relatively lower efficiency among near-field WPT technologies poses a considerable limitation. The resonator circuit indicates that energy oscillates at a resonant frequency between the inductor and capacitor before being dissipated in the resistor. The resonator's quality factor, Q, and resonant frequency, ω_0, are given by (1) and (2). These expressions are critical for understanding and designing WPT systems to enhance their performance and efficiency.

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{1}$$

$$Q = \frac{\omega_0}{2\Gamma} = \sqrt{\frac{L}{C}}\frac{1}{R} = \frac{\omega_0 L}{R} \tag{2}$$

To enhance the system's efficiency, strategic integration of compensation capacitors is essential. The study employs a series-series (SS) topology, wherein the compensating capacitors are connected in series with both primary and secondary coils as illustrated in Figure 2. A distinctive advantage of the SS topology is the capacitors' operational independence from resistive loads and mutual inductance, ensuring system resonance and reduced sensitivity to coil misalignment [21]-[24]. However, this configuration necessitates the presence of the secondary coil for energy transmission, as its absence can cause damage to the primary circuit. Misalignment affects mutual inductance and, consequently, the coupling coefficient, which are critical for system efficiency. The study will further elaborate on these dynamics and provide a formula for calculating the appropriate capacitor values to maintain system performance, as in (3) [25]-[27].

$$C = \frac{1}{\omega^2 L} \tag{3}$$

In this paper, the effect of switching frequency on WPT system efficiency is evaluated. Through rigorous experimentation, it quantifies efficiency across frequency ranges, pinpointing an optimal frequency band for enhanced WPT efficiency. The findings demonstrate considerable efficiency gains within these bands, informing WPT system design and optimization. The research contributes to a deeper understanding of the relationship between switching frequency and WPT efficiency, advocating for strategic frequency selection to optimize performance.

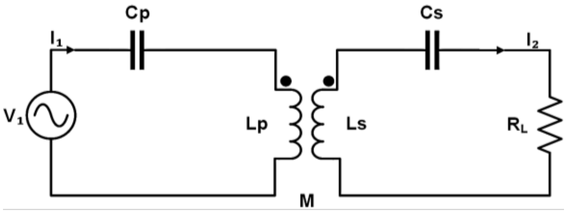

Figure 2. SS topology

2. METHODOLOGY

The methodology for optimizing a WPT system involves a multi-step process, each designed to ensure maximum efficiency in power transmission from the source to the load wirelessly. Initially, the process involves converting direct current (DC) to alternating current (AC) using a full-bridge inverter powered by MOSFETs, a critical step that sets the stage for efficient energy transfer through electromagnetic fields.

The next stage focuses on the generation and transmission of the magnetic field from the transmitter to the receiver coil. This is achieved by passing the high-frequency AC through the transmitter coil, creating an oscillating magnetic field. The field then induces a voltage in the receiver coil located within the magnetic field's influence. The efficiency of this induction process is pivotal, as it directly impacts the amount of power that can be wirelessly transferred and ultimately utilized by the receiving device.

Finally, the induced AC voltage in the receiver coil is converted back to DC through a rectification process. This step is crucial for ensuring that the power can be efficiently utilized by the DC load or for charging batteries. The incorporation of a compensation circuit between the transmitter and receiver coils is a strategic move to maintain resonance, thereby enhancing the efficiency of power transfer across the system. This comprehensive methodology, illustrated in the flowchart, as shown in Figure 3 (see in Appendix), encapsulates the core principles of WPT while addressing the challenges of optimizing power transfer efficiency through careful design and component selection.

3. COMPUTER SIMULATION MODEL

The computer simulation model section delineates a comprehensive simulation strategy for a WPT system, as conceptualized in a MATLAB schematic model, illustrated in Figure 4. This simulation mirrors the physical experimental setup, initiating with a 36 V DC power source linked to a full-bridge inverter via a pulse generator. The procedure begins at a 50 kHz switching frequency, which is systematically varied from 20 kHz to 100 kHz in 10 kHz steps, to assess the impact of frequency changes on system performance. The transmitter and receiver coil specifications align with those detailed in Table 1, under a constant load condition to ensure consistency in measurement and analysis.

A notable adjustment in the simulation model is the incorporation of a 50-fold gain at the input current. This modification is essential for enhancing the visibility of the current in relation to the voltage in the simulation output, considering the minimal current levels involved. This adjustment ensures that the current and voltage appear in phase with each other, facilitating a more accurate and clear interpretation of the simulation results.

The simulation model, through its detailed replication of the experimental setup and thoughtful adjustments such as the input current gain, provides a valuable tool for theoretical exploration and validation of the experimental findings. By closely mirroring the physical system's parameters and conditions within the MATLAB environment, the methodology offers a rigorous framework for analyzing the impact of switching frequency variations on WPT system efficiency, contributing to the broader understanding of optimal system design and operation.

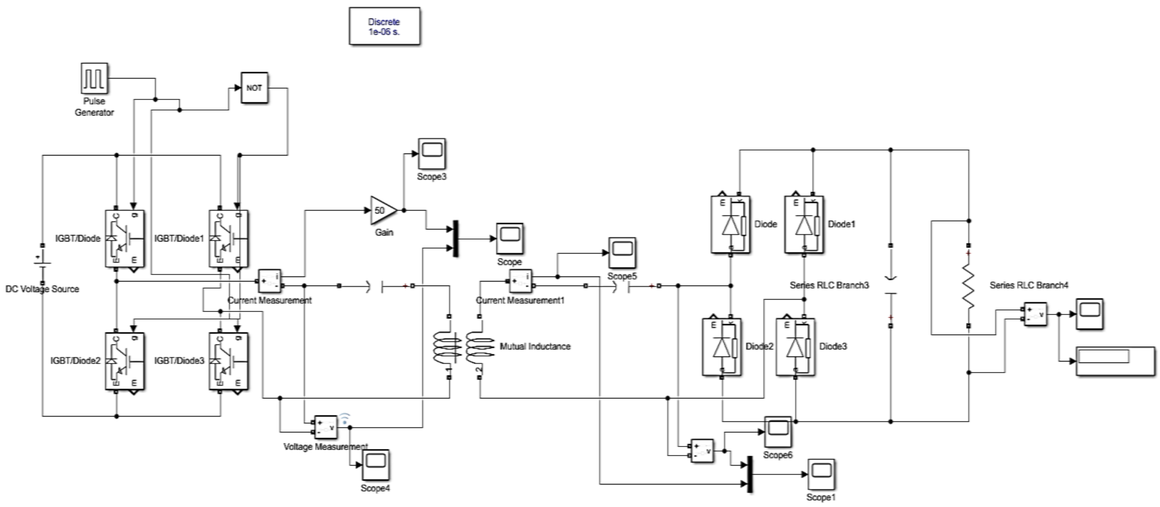

Figure 4. MATLAB simulation model for the proposed system

Table 1. The parameters of the proposed system

Parameters	Symbol	Value
Input voltage	V_s	36V
Transmitter inductance	L_p	24μH
Receiver inductance	L_s	24μH
Coupling coefficient	k	0.5
Quality factor	Q	180
Compensation capacitor	C_p, C_s	6.64μF
DC capacitor	C_o	200μF
Load	R	200Ω

4. EXPERIMENTAL SETUP

The experimental setup section meticulously outlines the setup for a laboratory-scale WPT system prototype as shown in Figure 5. Initially, the setup involves a 36 V DC power supply connected to a full-bridge inverter, with the system starting at a 50 kHz switching frequency. This baseline frequency is critical for driving the transmitter coil with a 3 A supply current, establishing the initial conditions for the experiment.

The experimental further encompasses systematic adjustments to the switching frequency, incrementing and decrementing in 10 kHz steps up to 100 kHz and down to 10 kHz from the base value. This range allows for a comprehensive evaluation of how varying switching frequencies affect the efficiency of power transfer across the system. The use of Wurth Elektronik wireless power charging coils, characterized by a 24μH inductance and a 13mm air gap, ensures that the setup is consistent with industry standards for WPT systems.

Efficiency measurements form a core part of the experimental procedure, focusing on the impact of switching frequency variations under a fixed load condition. By employing a resistive load for these measurements, the study isolates the effects of frequency changes on system efficiency. The meticulous of system parameters, as listed in Table 1, provides a clear framework for replicating the experimental conditions, ensuring that the findings are robust and can contribute valuable insights into the optimization of WPT systems.

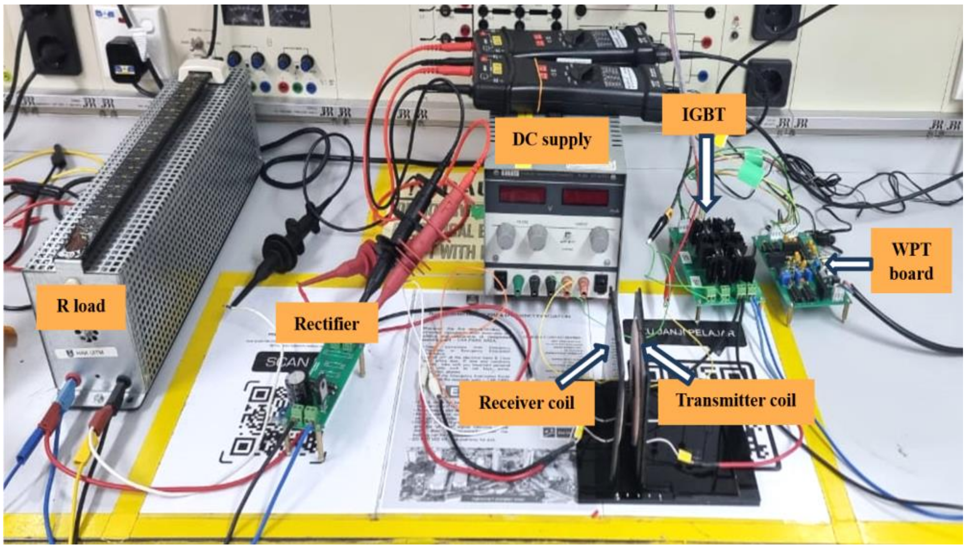

Figure 5. Photo of the experimental setup of the laboratory scale prototype system

5. RESULTS AND DISCUSSION

This section provided a rigorous analysis of the efficiency of WPT systems across varying switching frequencies. Figure 6 graphically represents the efficiency values against switching frequencies, showcasing both experimental and simulation results. Tables 2 and 3 further delineate these efficiency metrics for frequencies ranging from 20 kHz to 100 kHz in 10 kHz increments. This structured approach underscores the critical relationship between switching frequency and WPT efficiency, providing a comprehensive overview of system performance under different operational conditions.

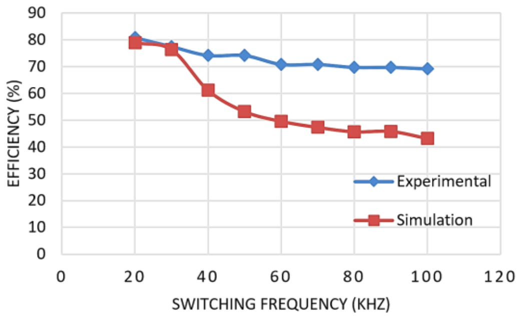

Figure 6. Power transfer efficiency of the WPT system against switching frequency

Table 2. Experimental result of switching frequencies and power transfer efficiency

Switching frequency (kHz)	Efficiency (%)
20	80.83
30	77.50
40	74.17
50	74.17
60	70.83
70	70.83
80	69.72
90	69.72
100	69.17

Table 3. Simulation result of switching frequencies and power transfer efficiency

Switching frequency (kHz)	Efficiency (%)
20	78.92
30	76.39
40	61.19
50	53.25
60	49.61
70	47.36
80	45.72
90	45.86
100	43.22

The experimental findings highlight a notable efficiency peak at lower switching frequencies, specifically at 20 kHz, where efficiency reached 80.83% experimentally and 78.92% in simulation. This phenomenon is attributed to reduced power losses in switching components such as transistors and diodes at lower frequencies, which results in slower switching transitions, and consequently, lower switching losses. This insight is pivotal for optimizing WPT systems, indicating a clear preference for lower switching frequencies to enhance overall efficiency.

Conversely, as the switching frequency increases, a decline in WPT efficiency is observed. This reduction is multifaceted, stemming from increased switching losses due to faster transitions in power electronic components and heightened conduction losses, including resistive and inductive losses within the circuit and coils. Moreover, elevated switching frequencies exacerbate electromagnetic interference (EMI) and compatibility (EMC) issues, potentially impacting the functionality of nearby electronic devices and the WPT system's efficiency.

Despite these trends being consistent across both experimental and simulation results, discrepancies between the two are evident, particularly as the switching frequency extends beyond 30kHz. These variances underscore the complexities of WPT systems and the challenges in precisely modeling their behavior. Nonetheless, MATLAB's simulation capabilities remain a valuable tool for predicting and analyzing these phenomena, offering insights into the nuances of WPT system performance across a spectrum of operational frequencies.

This comprehensive analysis not only provides a deeper understanding of the impact of switching frequency on WPT efficiency but also lays the groundwork for future optimizations. By balancing the trade-offs between lower frequency benefits and the challenges of higher frequencies, this research contributes significantly to the advancement of WPT technology, offering a roadmap for enhancing system design and performance.

6. CONCLUSION

In conclusion, this study meticulously explores the intricate dynamics of WPT systems, focusing on the pivotal role of switching frequencies in optimizing system efficiency. Through a series of methodical experiments and simulations, the study uncovers that lower switching frequencies significantly enhance the WPT system's efficiency by reducing resistive losses in the transmission medium. This discovery is pivotal, shedding light on the oft-overlooked aspect of frequency selection in the design and optimization of WPT systems.

Building upon the empirical data, the study further delves into the theoretical underpinnings that explain the observed efficiency improvements at lower frequencies. It provides a thorough analysis of the electromagnetic principles governing WPT systems, including the skin effect and its frequency-dependent nature. By correlating the empirical findings with theoretical models, the research establishes a robust framework for predicting WPT system performance based on frequency selection, thereby offering valuable insights for future system design and development.

In the broader context of renewable energy and sustainable technology development, this research contributes significantly to enhancing the practical viability of WPT systems. By identifying optimal frequency ranges that maximize efficiency while minimizing losses, the study paves the way for more energy-efficient, reliable, and cost-effective WPT solutions. This work not only advances the technical knowledge base in the field but also holds the promise of fostering innovation in the deployment of WPT technologies for various applications, from consumer electronics to electric vehicle charging systems, marking a significant step forward in the pursuit of a more sustainable and technologically advanced society.

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APPENDIX

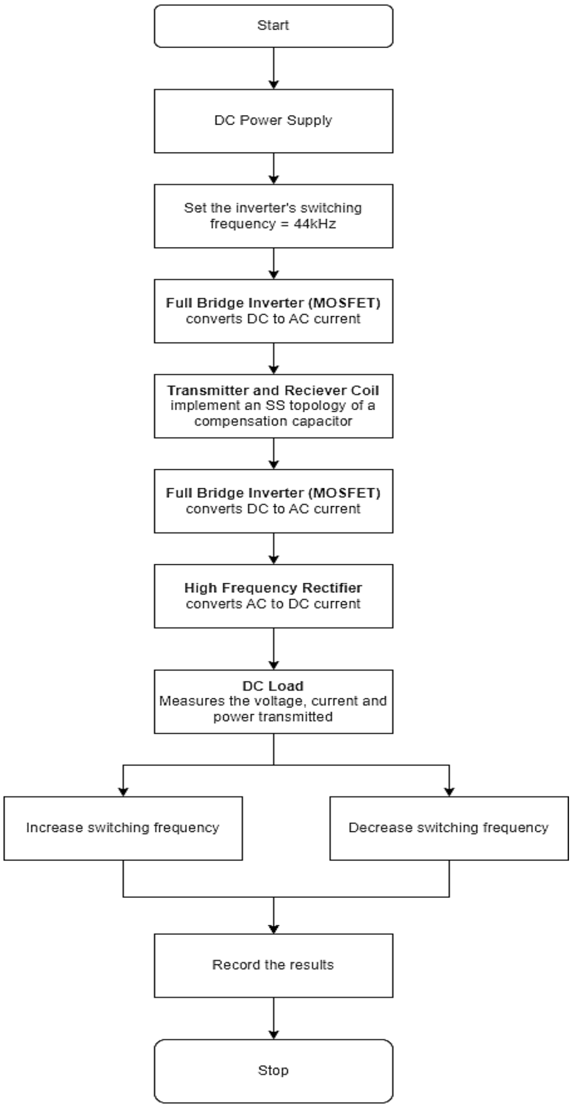

Figure 3. WPT flowchart operation

REFERENCES

[1] X. Hou, Z. Wang, Y. Su, Z. Liu, and Z. Deng, "A dual-frequency dual-load multirelay magnetic coupling wireless power transfer system using shared power channel," *IEEE Transactions on Power Electronics*, vol. 37, no. 12, pp. 15717–15727, Dec. 2022, doi: 10.1109/TPEL.2022.3190143.

[2] J. Wu, Y. Li, X. Dai, R. Gao, and M. He, "A dynamic power transfer route construction and optimization method considering random node distribution for wireless power transfer network," *IEEE Transactions on Power Electronics*, vol. 39, no. 4, pp. 4858–4869, Apr. 2024, doi: 10.1109/TPEL.2023.3348103.

[3] J. Wu, Z. Jin, X. Han, W. Zhang, Q. Zhao, and Z. Liang, "Construction and optimization of power transfer route in array wireless power transfer network with multiple load nodes," *IEEE Transactions on Power Electronics*, vol. 39, no. 3, pp. 3842–3850, Mar. 2024, doi: 10.1109/TPEL.2023.3339974.

[4] W. Xiong *et al.*, "A dual-frequency-detuning method for improving the coupling tolerance of wireless power transfer," *IEEE Transactions on Power Electronics*, vol. 38, no. 6, pp. 6923–6928, Jun. 2023, doi: 10.1109/TPEL.2023.3253904.

[5] Z. Deng *et al.*, "Design of a 60-kW EV dynamic wireless power transfer system with dual transmitters and dual receivers," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 12, no. 1, pp. 316–327, Feb. 2024, doi: 10.1109/JESTPE.2023.3301579.

[6] H. Ojukwu, B.-C. Seet, and S. U. Rehman, "Metasurface-aided wireless power transfer and energy harvesting for future wireless networks," *IEEE Access*, vol. 10, pp. 52431–52450, 2022, doi: 10.1109/ACCESS.2022.3170106.

[7] S. Li, L. Wang, Y. Guo, and Z. Liu, "Flexible energy-transfer control of dynamic wireless power transfer system based on estimation of load and mutual inductance," *IEEE Transactions on Industry Applications*, vol. 58, no. 1, pp. 1157–1167, Jan. 2022, doi: 10.1109/TIA.2021.3096173.

[8] S. Y. Chu, X. Cui, X. Zan, and A.-T. Avestruz, "Transfer-power measurement using a non-contact method for fair and accurate metering of wireless power transfer in electric vehicles," *IEEE Transactions on Power Electronics*, vol. 37, no. 2, pp. 1244–1271, Feb. 2022, doi: 10.1109/TPEL.2021.3105689.

[9] M. Venkatesan, R. Narayanamoorthi, K. M. AboRas, and A. Emara, "Efficient bidirectional wireless power transfer system control using dual phase shift PWM technique for electric vehicle applications," *IEEE Access*, vol. 12, pp. 27739–27755, 2024, doi: 10.1109/ACCESS.2024.3367437.

[10] K. Y. Lum, J.-S. Chow, and K. H. Yiauw, "Wireless power transfer framework for minirobot based on resonant inductive coupling and impedance matching," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, pp. 317–325, Mar. 2020, doi: 10.11591/ijpeds.v11.i1.pp317-325.

[11] M. Q. I. M. Zamani, R. Baharom, and D. Johari, "Conceptual study on grid-to-vehicle (G2V) wireless power transfer using single-phase matrix converter," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 3, pp. 1382–1388, Sep. 2019, doi: 10.11591/ijpeds.v10.i3.pp1382-1388.

[12] M. Rehman, P. Nallagownden, and Z. Baharudin, "Efficiency investigation of SS and SP compensation topologies for wireless power transfer," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 4, p. 2157, Dec. 2019, doi: 10.11591/ijpeds.v10.i4.pp2157-2164.

[13] W. C. Brown, "The history of wireless power transmission," *Solar Energy*, vol. 56, no. 1, pp. 3–21, Jan. 1996, doi: 10.1016/0038-092X(95)00080-B.

[14] H. Hertz and J. F. Mulligan, *Heinrich Rudolf Hertz (1857-1894): a collection of articles and addresses*. Routledge, 2019. doi: 10.4324/9780429198960.

[15] N. Tesla, W. W. Massie, and C. R. Underhill, "The future of the wireless art," in *Wireless telegraphy and telephony*, 1908. [Online]. Available: https://www.manhattanrarebooks.com/pages/books/1846/nikola-tesla-walter-w-massie-charles-r-underhill/the-future-of-the-wireless-art-in-wireless-telegraphy-and-telephony?soldItem=true

[16] A. Karalis, J. D. Joannopoulos, and M. Soljačić, "Efficient wireless non-radiative mid-range energy transfer," *Annals of Physics*, vol. 323, no. 1, pp. 34–48, Jan. 2008, doi: 10.1016/j.aop.2007.04.017.

[17] J. Huang, Y. Zhou, Z. Ning, and H. Gharavi, "Wireless power transfer and energy harvesting: current status and future prospects," *IEEE Wireless Communications*, vol. 26, no. 4, pp. 163–169, Aug. 2019, doi: 10.1109/MWC.2019.1800378.

[18] P. S. Patil and S. Padaganur, "Challenging issues in wireless power transmission methods: A survey," *International Journal of Scientific and Technology Research*, vol. 7, no. 8, pp. 136–139, 2018.

[19] K. Detka and K. Górecki, "Wireless power transfer—a review," *Energies*, vol. 15, no. 19, p. 7236, Oct. 2022, doi: 10.3390/en15197236.

[20] R. Baharom, M. N. Seroji, M. K. M. Salleh, and K. S. Muhammad, "Impact of switching frequency variation to the power transfer efficiency of wireless power transfer converter," in *2016 IEEE Symposium on Computer Applications & Industrial Electronics (ISCAIE)*, May 2016, pp. 127–131. doi: 10.1109/ISCAIE.2016.7575050.

[21] Y. Yao, X. Liu, Y. Wang, and D. Xu, "LC/CL compensation topology and efficiency-based optimisation method for wireless power transfer," *IET Power Electronics*, vol. 11, no. 6, pp. 1029–1037, May 2018, doi: 10.1049/iet-pel.2017.0875.

[22] N. Jamal, S. Saat, Y. Yusmarnita, T. Zaid, and A. A. M. Isa, "Investigations on capacitor compensation topologies effects of different inductive coupling links configurations," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 6, no. 2, pp. 274–281, Jun. 2015, doi: 10.11591/ijpeds.v6.i2.pp274-281.

[23] S. Li, W. Li, J. Deng, T. D. Nguyen, and C. C. Mi, "A double-sided LCC compensation network and its tuning method for wireless power transfer," *IEEE Transactions on Vehicular Technology*, vol. 64, no. 6, pp. 2261–2273, Jun. 2015, doi: 10.1109/TVT.2014.2347006.

[24] N. Rasekh and M. Mirsalim, "Evaluation study on an integration method for a DDQP using LCC and series compensation topologies for inductive power transfer," *IET Electric Power Applications*, vol. 12, no. 9, pp. 1320–1327, Nov. 2018, doi: 10.1049/iet-epa.2017.0825.

[25] K. Fotopoulou and B. W. Flynn, "Wireless power transfer in loosely coupled links: coil misalignment model," *IEEE Transactions on Magnetics*, vol. 47, no. 2, pp. 416–430, Feb. 2011, doi: 10.1109/TMAG.2010.2093534.

[26] Z. Li and J. Yi, "Modeling and design of a transmission coil and four cascaded receiving coils wireless charging structure with lateral misalignments," *IEEE Access*, vol. 8, pp. 75976–75985, 2020, doi: 10.1109/ACCESS.2020.2988888.

[27] C. Zheng, H. Ma, J.-S. Lai, and L. Zhang, "Design considerations to reduce gap variation and misalignment effects for the inductive power transfer system," *IEEE Transactions on Power Electronics*, vol. 30, no. 11, pp. 6108–6119, Nov. 2015, doi: 10.1109/TPEL.2015.2424893.

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