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A single-stage constant-power and optimal-efficiency double-sided LCC wireless battery charger

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ABSTRACT

This article proposes a novel single-stage double-sided LCC (DS-LCC) constant power (CP) wireless battery charger. The proposed CP charger uses a closed-loop control in the secondary side with the active rectifier to make the DS-LCC charger achieve CP charging and optimal efficiency. Compared to previous work, the proposed CP wireless power transfer system does not involve any switch-controlled capacitor (SCC), does not require wireless communication, and can achieve optimal efficiency throughout the charging process. The proposed charger reduces cost and system complexity while improving efficiency. The proposed wireless charger is validated by simulation, and the efficiency remains between 94.44% and 94.52%, surpassing the previous work.

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1. INTRODUCTION

Conventional constant current (CC) charging is a primary method in battery charging technology [1], [2]. Despite its widespread use, this approach has a significant limitation. The power delivered is comparatively low at the initial phase of CC charging because of the battery's initial low voltage, as depicted in Figure 1(a). This charging method fails to optimize the power potential of the charger or power source, resulting in a lower overall charging rate.

The constant power (CP) charging technique was developed to enhance charging efficiency [3]. The output power is maintained at its maximum level to fully leverage the power capacity of the charger or source, as illustrated in Figure 1(b). This method accelerates the charging process and reduce charging time. Furthermore, CP charging helps alleviate battery degradation concerns [4], [5].

The wireless charging technology has been widely adopted by various fields, like biomedical implants [6]-[8], electric transportations [4], [5], [9]-[11], and consumer electronics [12]-[14]. Inductive power transfer (IPT) wireless chargers have gained significant attention due to their hands-free operation, low maintenance, high reliability, and safety. A common method for achieving CP charging in the wireless charger involves adding extra DC-DC converters [15], [16]. However, the additional stage increases system complexity, cost, and losses. Various single-stage wireless charging solutions have been proposed to eliminate the extra DC-DC stage. Among them, single-stage CP wireless chargers based on the series-series (S-S) compensation topology have been introduced [17]-[19]. Nevertheless, these S-S wireless chargers experience excessive current issues during misalignment, requiring additional safety mechanisms for protection.

The LCC compensation topology, like LCC-S and double-sided LCC (DS-LCC), effectively mitigates this issue. An LCC-S CP charger using pulse density modulation (PDM) is proposed in [5]. However, this type of charger does not support bidirectional operation, making it unsuitable for the evolving demands of the internet of energy. DS-LCC compensation topology can operate bidirectionally and provide several key benefits, including high efficiency upper limit, load-independent constant current output, and enhanced flexibility in parameter design [1], [20]-[22]. Recognized by industry standards [23], this topology is widely adopted in wireless power transfer (WPT) systems.

However, the conventional single-stage DS-LCC wireless charger is limited to CC charging. To enable CP charging, authors in [21] proposes the DS-LCC wireless charger with two additional switch-controlled capacitors (SCCs). While this modification achieves CP output, it also introduces higher costs and power losses. Additionally, this CP charger does not consistently achieve optimal efficiency throughout the charging process. This article presents a novel single-stage DS-LCC CP wireless charger that eliminates the need for SCCs, thereby reducing system costs. Moreover, it consistently achieves load impedance matching to maintain optimal efficiency.

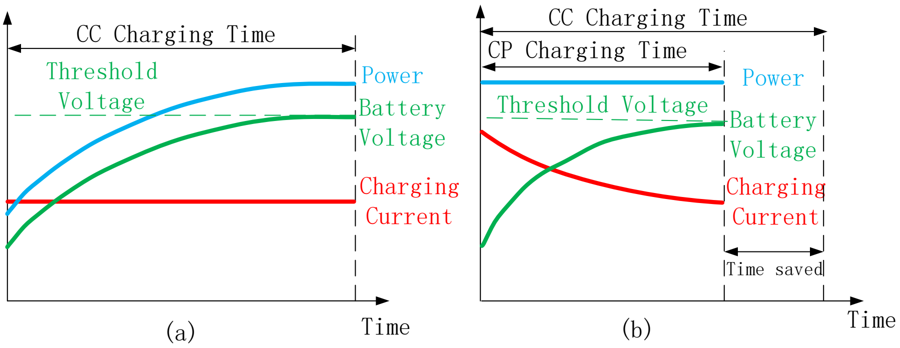

Figure 1. Charging profile of (a) CC charging and (b) CP charging

2. METHODOLOGY

2.1. System structure

The structure of the proposed CP wireless charger is depicted in Figure 2. An inverter with four MOSFETs (S_1-S_4) generates an AC voltage source to supply power to the resonant circuit. L_1, C_1, C_p, L_p, and R_p correspond to the series inductor, parallel capacitor, series-compensated capacitor, self-inductance, and the resistance of the coil respectively on the primary side. Similarly L_2, C_2, C_s, L_s, and R_s fulfill equivalent roles on the secondary side.

An active rectifier, consisting of four MOSFETs (S_5, S_6, S_7, S_8), is employed for AC-DC conversion. The DC-link capacitors, C_{in} and C_O, are incorporated to smooth the voltage, while V_1, V_2 represent the input DC voltage and battery voltage. u_{ab} and i_{L1} denote the output voltage and current of the inverter, respectively, while u_{cd} and i_{L2} represent the input voltage and current of the rectifier. i_{o1} is the current between the DC-link capacitors C_O and battery. The mutual inductance between the two coils is denoted as M, and the coupling coefficient k is given by: $k = M\sqrt{L_pL_s}$. This system topology is symmetrical, so it has the ability to achieve bidirectional operation.

2.2. Control strategy for CP charging

With the implementation of the active rectifier, the u_{cd} waveform can be shaped into a square wave through phase shift control [24], allowing its pulse width W to be adjusted, as depicted in Figure 3. The corresponding waveforms of i_{L2} and i_{o1} are shown in Figure 4, where the pulse width of i_{o1} corresponds to that of u_{cd} and remains adjustable. As a result, the output current I_o can be controlled by varying the pulse width of u_{cd}.

Figure 5 illustrates the proposed control strategy. The predefined rated output power is represented by $P_{o,\text{rated}}$. The reference current $I_{o,\text{ref}}$ is computed by the divider based on $P_{o,\text{rated}}$ and the battery voltage

V_2, serving as the command input for the closed-loop current control system. To generate the gate signals for MOSFETs S_5, S_6, S_7, and S_8, the modulator detects zero-crossing points by monitoring the input current i_{L2} of the active rectifier.

The hysteresis control algorithm is used in current close loop control, as depicted in Figure 6. If I_o lower than $I_{o,\text{ref}} - \Delta i$, the pulse width ($W$) will increase, whereas if I_o higher than $I_{o,\text{ref}} + \Delta i$, W will decrease. This mechanism ensures that I_o remains within the specified tolerance band. Since the battery voltage changes gradually during the charging process, the dynamic response of the control algorithm is not a significant concern. With the proposed strategy, the output power remains effectively constant.

To demonstrate how the proposed wireless charger achieves optimal efficiency, a fundamental harmonic analysis (FHA) model is developed, as illustrated in Figure 7. In this model, $X_1 = \omega L_1$, $X_2 = \omega L_2$ represent the characteristic reactance in the primary side and secondary side. The variables u_p and u_s correspond to the fundamental harmonics of u_{ab} and u_{cd}, respectively. U_p and U_s represent the RMS value of u_p and u_s. $\dot{U}_p$ and $\dot{U}_s$ represent the phasor forms of u_p and u_s.

As stated in [25], optimal efficiency is achieved when $U_p = U_s$. In the proposed wireless charger, the DS-LCC compensation network's characteristic ensures that the current $\dot{I}_{L2}$ flowing through L_2 remains constant. Additionally, the constant power control strategy make output power P_o constant. Neglecting the loss of the active rectifier, the U_s can express as (1).

$$U_s = P_o/I_{L2} \tag{1}$$

Consequently, U_s is also constant during the charging process. Therefore, by designing the charger to satisfy $U_s = U_p$, the wireless charger can maintain optimal efficiency throughout the entire constant power charging process.

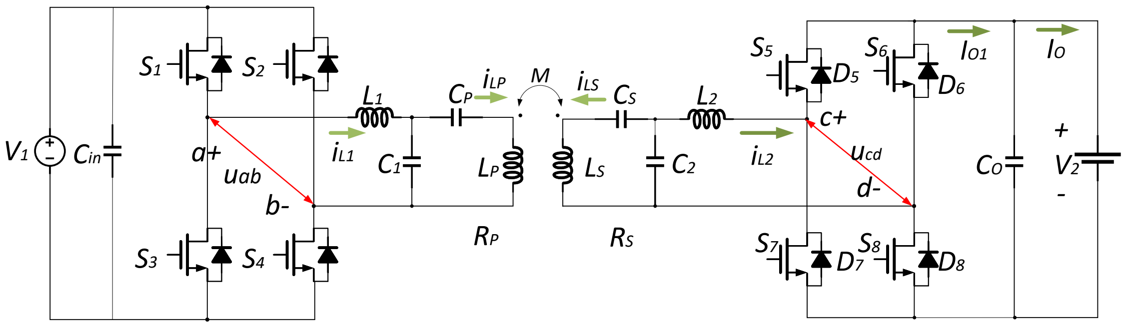

Figure 2. Topology of the proposed wireless charger

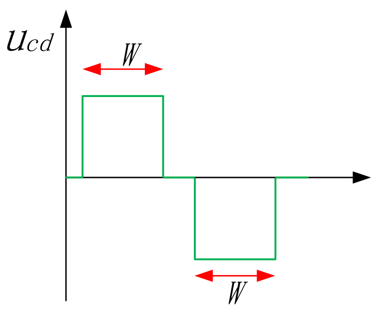

Figure 3. u_{cd} waveform with the active rectifier

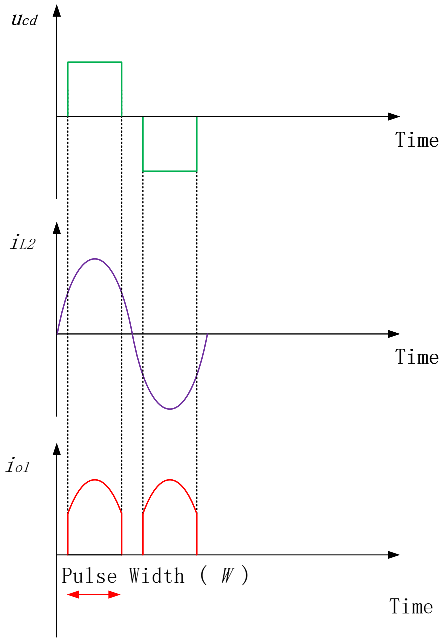

Figure 4. i_{o1} waveforms of proposed operating method

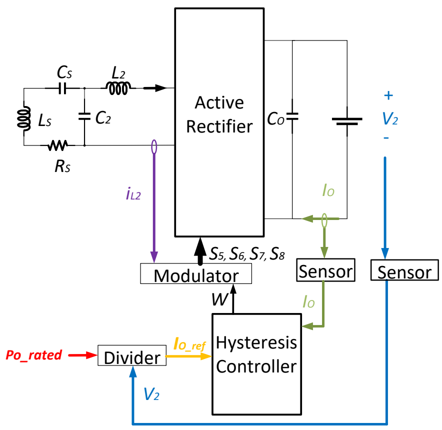

Figure 5. Control schematic diagram

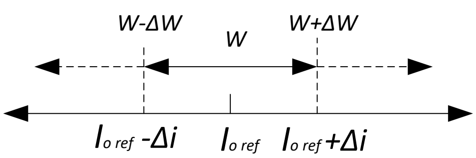

Figure 6. Hysteresis control for current regulation

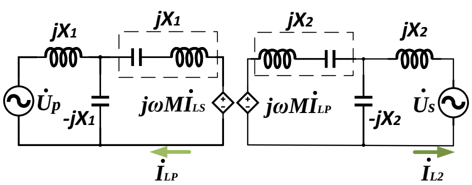

Figure 7. FHA model of the proposed wireless charger

3. SIMULATION RESULTS AND DISCUSSION

3.1. Specifications

The proposed CP wireless charger is verified by conducting a simulation in Simulink. The parameters were designed according to [1]. Other details of the simulation are listed in Table 1.

3.2. Simulation results

Figure 8 illustrates the variations in output power P_o and output current I_o with respect to the output voltage V_2. As V_2 increases from 40 V to 60 V, I_o decreases from 1.723 A to 1.137 A. Meanwhile, CP charging is achieved, with P_o remaining within the range of 67.842 W to 68.875 W. CP charging can be achieved by the proposed charger.

The waveforms of the output voltage u_{ab} and output current i_{L1} of the inverter are shown in Figure 9. Zero-voltage switching (ZVS) is consistently achieved in the inverter. This advantage is inherited from the traditional DS-LCC wireless power transfer system [1]. Figure 10 illustrates the DC-to-DC efficiency during the charging process. The efficiency ranges from 94.44% to 94.52%, which is higher than the 87.5%–91.5% efficiency of the CP wireless charger proposed in [21].

Table 1. Parameters of the wireless charger

Symbol	Parameter	Value
V_1	Input DC voltage	40 V
V_2	Battery voltage (output DC voltage)	40 V - 60 V
k	Coupling coefficient	0.3
L_P	Transmitting coil inductance	111 μH
L_S	Receiving coil inductance	111 μH
R_{Lp}	Transmitting coil resistance	0.2 Ω
R_{Ls}	Receiving coil resistance	0.2 Ω
L_1	Primary compensation inductance	35 μH
L_2	Secondary compensation inductance	35 μH
R_{L1}	Primary compensation inductor resistance	0.07 Ω
R_{L2}	Secondary compensation inductor resistance	0.07 Ω
C_1	Primary parallel capacitance	116 nF
C_2	Secondary parallel capacitance	116 nF
C_P	Primary series capacitance	54 nF
C_S	Secondary series capacitance	60 nF
f	Switching frequency	79 kHz
R_{ON1}	Inverter's MOSFET on-state resistance	100 mΩ
R_{ON2}	Rectifier's MOSFET on-state resistance	100 mΩ
P_{ref}	Reference power	68 W

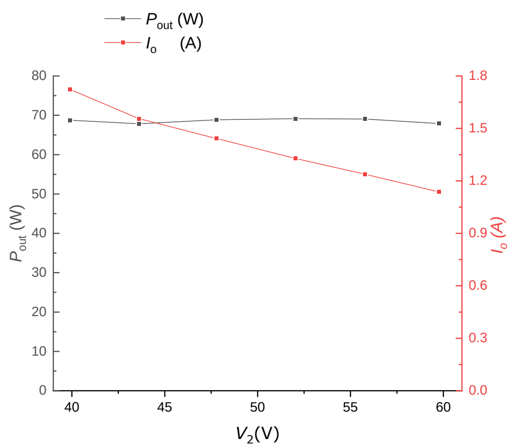

Figure 8. Output current I_o, and output power Po versus the different battery voltage V_2 in simulation

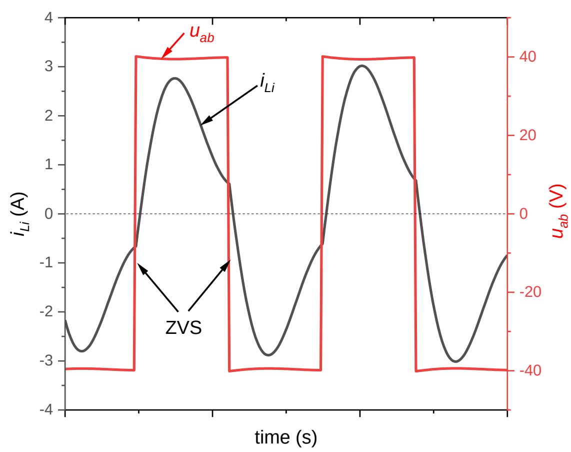

Figure 9. Waveforms of inverter's input voltage u_{ab} and current i_{L1}

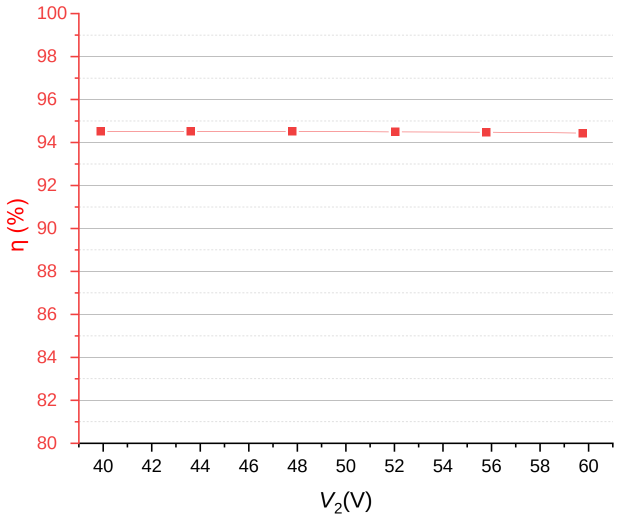

Figure 10. Efficiency during the CP charging

4. CONCLUSION

This work proposes a single-stage CP DS-LCC wireless charger with the corresponding control strategy, eliminating the need for any SCC. The proposed CP charger can achieve CP charging and optimum efficiency simultaneously. The simulation is conducted to evaluate the performance of the proposed wireless charger. The result shows that the proposed wireless charger maintains an efficiency of 94.44% to 94.52% throughout the charging process, surpassing the performance of the previous work.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
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Mohd Junaidi Abdul Aziz		✓				✓	✓			✓		✓	✓	✓
Nik Rumzi Nik Idris		✓				✓	✓			✓		✓	✓	
Tole Sutikno						✓	✓			✓		✓		

C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal Analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject Administration
Fu : **Fu**nding Acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author upon reasonable request.

REFERENCES

[1] 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, 2015, doi: 10.1109/TVT.2014.2347006.

[2] V. B. Vu, D. H. Tran, and W. Choi, "Implementation of the constant current and constant voltage charge of inductive power transfer systems with the double-sided LCC compensation topology for electric vehicle battery charge applications," *IEEE Transactions on Power Electronics*, vol. 33, no. 9, pp. 7398–7410, 2018, doi: 10.1109/TPEL.2017.2766605.

[3] R. Tanikawa and H. Le, *"Constant power battery charger,"* WO1996037941A1, 1996 [Online]. Available: https://patents.google.com/patent/WO1996037941A1

[4] Z. Huang, S. C. Wong, and C. K. Tse, "Design of a single-stage inductive-power-transfer converter for efficient EV battery charging," *IEEE Transactions on Vehicular Technology*, vol. 66, no. 7, pp. 5808–5821, 2017, doi: 10.1109/TVT.2016.2631596.

[5] I. W. Iam, C. K. Choi, C. S. Lam, P. I. Mak, and R. P. Martins, "A constant-power and optimal-transfer-efficiency wireless inductive power transfer converter for battery charger," *IEEE Transactions on Industrial Electronics*, vol. 71, no. 1, pp. 450–461, 2024, doi: 10.1109/TIE.2023.3241408.

[6] Q. Chen, S. C. Wong, C. K. Tse, and X. Ruan, "Analysis, design, and control of a transcutaneous power regulator for artificial hearts," *IEEE Transactions on Biomedical Circuits and Systems*, vol. 3, no. 1, pp. 23–31, 2009, doi: 10.1109/TBCAS.2008.2006492.

[7] A. Aldaoud *et al.*, "Near-field wireless power transfer to stent-based biomedical implants," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 2, no. 3, pp. 193–200, 2018, doi: 10.1109/JERM.2018.2833386.

[8] M. Machnoor and G. Lazzi, "High-efficiency multicoil wireless power and data transfer for biomedical implants and neuroprosthetics," *Antenna and Sensor Technologies in Modern Medical Applications*, pp. 277–318, 2021, doi: 10.1002/9781119683285.ch8.

[9] Z. Bi, T. Kan, C. C. Mi, Y. Zhang, Z. Zhao, and G. A. Keoleian, "A review of wireless power transfer for electric vehicles: Prospects to enhance sustainable mobility," *Applied Energy*, vol. 179, pp. 413–425, 2016, doi: 10.1016/j.apenergy.2016.07.003.

[10] R. Mai, Y. Chen, Y. Zhang, N. Yang, G. Cao, and Z. He, "Optimization of the passive components for an S-LCC topology-based WPT system for charging massive electric bicycles," *IEEE Transactions on Industrial Electronics*, vol. 65, no. 7, pp. 5497–5508, 2018, doi: 10.1109/TIE.2017.2779437.

[11] H. Zhang, F. Lu, and C. Mi, "An electric roadway system leveraging dynamic capacitive wireless charging: Furthering the continuous charging of electric vehicles," *IEEE Electrification Magazine*, vol. 8, no. 2, pp. 52–60, 2020, doi: 10.1109/MELE.2020.2985486.

[12] S. Y. R. Hui and W. C. Ho, "A new generation of universal contactless battery charging platform for portable consumer electronic equipment," *PESC Record - IEEE Annual Power Electronics Specialists Conference*, vol. 1, pp. 638–644, 2004, doi: 10.1109/pesc.2004.1355823.

[13] L. Zhou, J. Tian, S. Liu, R. Mai, L. Fu, and U. K. Madawala, "High-efficiency WPT systems for potable electronics based on DC-bias-voltage-controlled variable capacitor," *IEEE Transactions on Industrial Electronics*, vol. 71, no. 5, pp. 4707–4718, 2024, doi: 10.1109/TIE.2023.3281675.

[14] Y. Zhang, S. Chen, X. Li, and Y. Tang, "Design methodology of free-positioning nonoverlapping wireless charging for consumer electronics based on antiparallel windings," *IEEE Transactions on Industrial Electronics*, vol. 69, no. 1, pp. 825–834, 2022, doi: 10.1109/TIE.2020.3048322.

[15] X. Dai, X. Li, Y. Li, and A. P. Hu, "Maximum efficiency tracking for wireless power transfer systems with dynamic coupling coefficient estimation," *IEEE Transactions on Power Electronics*, vol. 33, no. 6, pp. 5005–5015, 2018, doi: 10.1109/TPEL.2017.2729083.

[16] Y. Liu and H. Feng, "Maximum efficiency tracking control method for WPT system based on dynamic coupling coefficient identification and impedance matching network," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 8, no. 4, pp. 3633–3643, 2020, doi: 10.1109/JESTPE.2019.2935219.

[17] H. Zhu, B. Zhang, and L. Wu, "Output power stabilization for wireless power transfer system employing primary-side-only control," *IEEE Access*, vol. 8, pp. 63735–63747, 2020, doi: 10.1109/ACCESS.2020.2983465.

[18] Z. Huang, C. S. Lam, P. I. Mak, R. P. D. S. Martins, S. C. Wong, and C. K. Tse, "A single-stage inductive-power-transfer converter for constant-power and maximum-efficiency battery charging," *IEEE Transactions on Power Electronics*, vol. 35, no. 9, pp. 8973–8984, 2020, doi: 10.1109/TPEL.2020.2969685.

[19] F. Xu, S. C. Wong, and C. K. Tse, "Overall loss compensation and optimization control in single-stage inductive power transfer converter delivering constant power," *IEEE Transactions on Power Electronics*, vol. 37, no. 1, pp. 1146–1158, 2022, doi: 10.1109/TPEL.2021.3098914.

[20] M. Mohammad *et al.*, "Bidirectional LCC-LCC-compensated 20-kW wireless power transfer system for medium-duty vehicle charging," *IEEE Transactions on Transportation Electrification*, vol. 7, no. 3, pp. 1205–1218, 2021, doi: 10.1109/TTE.2021.3049138.

[21] Z. Luo, Y. Zhao, M. Xiong, X. Wei, and H. Dai, "A self-tuning LCC/LCC system based on switch-controlled capacitors for constant-power wireless electric vehicle charging," *IEEE Transactions on Industrial Electronics*, vol. 70, no. 1, pp. 709–720, 2023, doi: 10.1109/TIE.2022.3153812.

[22] W. Li, H. Zhao, J. Deng, S. Li, and C. C. Mi, "Comparison study on SS and double-sided LCC compensation topologies for EV/PHEV wireless chargers," *IEEE Transactions on Vehicular Technology*, vol. 65, no. 6, pp. 4429–4439, 2016, doi: 10.1109/TVT.2015.2479938.

[23] China Electricity Council, *"GB/T 38775.6 Electric vehicle wireless power transfer—Part 6: Interoperability requirements and testing—Ground side,"* 2022. [Online]. Available: https://www.gbstandards.org/China_standard_english.asp?code=GB/T 38775.6-2021

[24] Y. Li, J. Hu, F. Chen, Z. Li, Z. He, and R. Mai, "Dual-phase-shift control scheme with current-stress and efficiency optimization for wireless power transfer systems," *IEEE Transactions on Circuits and Systems I: Regular Papers*, vol. 65, no. 9, pp. 3110–3121, 2018, doi: 10.1109/TCSI.2018.2817254.

[25] N. Fu, J. Deng, Z. Wang, and D. Chen, "An LCC-LCC compensated WPT system with switch-controlled capacitor for improving efficiency at wide output voltages," *IEEE Transactions on Power Electronics*, vol. 38, no. 7, pp. 9183–9194, 2023, doi: 10.1109/TPEL.2023.3260207.

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