Wireless Power Transfer for Smart Industrial and Home Applications

AS THE key technique of smart industrial process and household applications, Internet of Things (IoT) connects devices via Internet to realize information sharing, intelligent control, remote monitoring, data statistics, etc., which significantly improve the intelligence, flexibility, and convenience for our industrial production and daily life. Along with more and more movable electric-driving devices to join the IoT, the energy supply is an increasingly serious technique issue for smart industrial and household applications [item 1) in the Appendix]. Wireless power transfer (WPT) exhibits increasing attractions for various electric-driving devices, where the energy can be cordlessly harnessed from soft mediums (electromagnetic field, microwave, laser etc.) in air to charge the battery in dynamic states or extreme operation conditions. Accordingly, with the help of advantages of IoT, this epoch-making energy-transmission technique will show significant meanings to deal with the access, exchange, and management of electric energy. This special section on "Wireless Power Transfer for Smart Industrial and Home Applications" of the IEEE Transactions on Industrial Electronics accepted 17 research papers with emphasis on the theoretical analysis, design, control strategies, management, coordination, and communication of WPT systems for smart industrial and household applications.

Technically, the topics of all these accepted manuscripts cover a wide range of important and challenging issues of WPT systems, which can be mainly grouped into the working mechanism and the emerging applications as shown in Table I.

- Working Mechanism: From the perspective of the compensation network, in [item 2) in the Appendix], the causes of the degradation in efficiency were analyzed, and an automatic impedance-matching method based on the feedforward-backpropagation neural network was proposed to maintain the power-transfer efficiency at a reasonable level. In [item 3) in the Appendix], a novel, simplified, and easy-to-follow set of design guidelines for series–series compensated RIPT systems is proposed. The design guidelines avoid bifurcation by calculating the parameters for a given load profile in a systematic and easy-to-follow manner. In [item 4) in the Appendix], a single capacitor and a single switch consisting of a tunable capacitor, and effective capacitance value determined by the pulsewidth modulation (PWM) ON/OFF duty ratio is presented. Furthermore, the PWM feedback loop is designed such that the power factor and real-part impedance of the *LCC* inverter is maximized, which the PWM switch is turned-ON at zero voltage and turned-OFF with a low dv/dt, minimizing switching losses.

TABLE I
CLASSIFICATION OF PAPERS PUBLISHED IN THE SPECIAL SECTION

Topic	Category		Items
Working mechanism	Compensation network		Items 2)–4) in the Appendix
	Transmission channel	Multiple receivers	Items 5) and 6) in the Appendix
		Power/communication	Item 7) in the Appendix
	Harmonics analysis		Item 8) in the Appendix
	CCPT (Capacitive coupling power transfer)		Item 9) in the Appendix
Applications	Household applications	Low power	Items 10)–12) in the Appendix
		High power(EVs)	Items 13) and 14) in the Appendix
	Industrial applications	Drone	Item 15) in the Appendix
		Implantable device	Item 16) in the Appendix
		High voltage monitor	Item 17) in the Appendix
		Rotary application	Item 18) in the Appendix

From the perspective of the transmission channel, in [item 5) in the Appendix], a new design of near-field focused metasurface for high-efficiency WPT with multifocus characteristics is proposed. A general synthesis procedure is outlined to design metasurfaces with desired multiple foci in the near-field zone, and the unit cell of printed tri-dipole is used to realize the focused metasurface. Meanwhile, a receiver that can adjust the output voltage of coil is proposed to simultaneously charge as many receivers of different couplings as possible is introduced in [item 6) in the Appendix]. In [item 7) in the Appendix], a dual-channel transmission model is constructed for integrating bi-directional data communication into a WPT system based on a single-coil and dual-resonant structure. Formulas for the Q value at the energy transmission channel, the bandwidth at the signal transmission channel, and the bi-directional crosstalk between the energy and signal transmission channels are also deduced.

Besides, in [item 8) in the Appendix], a comprehensive design foundation called multiple harmonics analysis is developed to analyze series–series compensated WPT systems, which provides a set of closed-form solutions to predict quantities such as zero-voltage switching and voltage gain. Meantime, a method to transfer power across a metal barrier wirelessly by combined capacitive and inductive coupling is proposed in [item 9) in the Appendix].

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- Applications: In terms of the smart home, [item 10) in the Appendix] introduces a method of integrating the function of wireless energy harvesting from ambient RF signals to a conventional quartz clock for home applications. The most attractive feature is that the clock itself is used as the power receiving device; thus, no additional antennas are needed. Meanwhile, a smartwatch strap wireless charging system is demonstrated and a wireless ballastless lighting system for fluorescent lamps is implemented in [items 11) and 12) in the Appendix], respectively. In [item 13) in the Appendix], a current hysteresis comparator is adopted to suppress the noise in high power, and an enhanced phase detection methodology is proposed to measure the phase of resonant current by using a reference signal produced by the processor. Based on the dynamical mutual inductance which can be calculated by using dc current input and load detection, a charging area can be determined for the requirement of the output power in [item 14) in the Appendix].

In terms of the industry, [item 15) in the Appendix] proposes a novel nonlinear parity-time-symmetric model, wherein the nonlinear saturable gain is provided by a self-oscillating controlled inverter, which is able to attain stable power transfer with high and constant transfer efficiency under a dynamic change of coupling condition. The [item 16) in the Appendix] presents a new effective sandwiched WPT system, which is adopted to recharge the battery of a micromedical robotics for cardiac pacemaker, in which the key of the design is to use the distinct sandwiched topology in both the transmitter and receiver coils. In [item 17) in the Appendix], a novel high-voltage operation featured WPT system for monitoring equipment charging at 110-kV high-voltage transmission line based on magnetic resonant coupling is studied and designed. An accurate reluctance model for CS is presented in this paper along with the associated parameter identification, considering the partial linking effect of the magnetic flux is designed in [item 18) in the Appendix].

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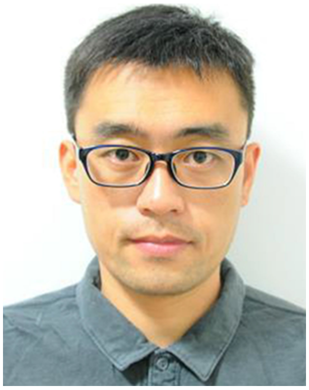
Appendix
Related Work

1) Z. Zhang, H. Pang, A. Georgiadis, and C. Cecati, "Wireless power transfer—An overview," *IEEE Trans. Ind. Electron.*, vol. 66, no. 2, pp. 1044–1058, Feb. 2019.
2) Y. Li, W. Dong, Q. Yang, J. Zhao, L. Liu, and S. Feng, "An automatic impedance matching method based on the feedforward-backpropagation neural network for a WPT system," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 3963–3972, May 2019.
3) 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, May 2019.
4) D.-H. Kim and D. Ahn, "Self-tuning *LCC* inverter using PWM-controlled switched capacitor for inductive wireless power transfer," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 3983–3992, May 2019.
5) S. Yu, H. Liu, and L. Li, "Design of near-field focused metasurface for high efficient wireless power transfer with multifocus characteristics," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 3993–4002, May 2019.
6) D. Ahn, S.-M. Kim, S.-W. Kim, J.-I. Moon, and I.-K. Cho, "Wireless power transfer receiver with adjustable coil output voltage for multiple receivers application," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4003–4012, May 2019.
7) L. Ji, L. Wang, C. Liao, and S. Li, "Simultaneous wireless power and bidirectional information transmission with a single-coil, dual-resonant structure," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4013–4022, May 2019.
8) Y. Fang and B. M. H. Pong, "Multiple harmonics analysis for variable frequency asymmetrical pulsewidth-modulated wireless power transfer systems," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4023–4030, May 2019.
9) W. Zhou, Y.-G. Su, L. Huang, X.-D. Qing, and A. P. Hu, "Wireless power transfer across metal barrier by combined capacitive and inductive coupling," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4031–4041, May 2019.
10) C. Song *et al.*, "A novel quartz clock with integrated wireless energy harvesting and sensing functions," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4042–4053, May 2019.
11) S. Jeong *et al.*, "Smartwatch strap wireless power transfer system with flexible PCB coil and shielding material," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4054–4064, May 2019.
12) C. Jiang, K. T. Chau, Y. Y. Leung, C. Liu, C. H. T. Lee, and W. Han, "Design and analysis of wireless ballastless fluorescent lighting," *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4065–4074, May 2019.

13) Y. Jiang, L. Wang, Y. Wang, J. Liu, X. Li, and G. Ning, “Analysis, design and implementation of accurate ZVS angle control for EV battery charging in wireless high-power transfer,” *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4075–4085, May 2019.
14) X. Dai, J.-C. Jiang, and J.-Q. Wu “Charging area determining and power enhancement method for multiexcitation unit configuration of wirelessly dynamic charging EV system,” *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4086–4096, May 2019.
15) J. Zhou, B. Zhang, W. Xiao, D. Qiu, and Y. Chen, “Nonlinear parity-time-symmetric model for constant efficiency wireless power transfer: Application to a drone-in-flight wireless charging platform,” *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4097–4107, May 2019.
16) C. Liu, C. Jiang, J. Song, and K. T. Chau, “An effective sandwiched wireless power transfer system for charging implantable cardiac pacemaker,” *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4108–4117, May 2019.
17) C. Cai *et al.*, “Resonant wireless charging system design for 110-kV high voltage transmission line monitoring equipment,” *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4118–4129, May 2019.
18) G. He, Q. Chen, X. Ren, S.-C. Wong, and Z. Zhang, “Modeling and design of contactless sliprings for rotary applications,” *IEEE Trans. Ind. Electron.*, vol. 66, no. 5, pp. 4130–4140, May 2019.



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