Guest Editorial: Special Issue on Advanced and Emerging Technologies of High Efficiency and Long-Distance Wireless Power Transfer Systems

WIRELESS power transfer (WPT) technology has become a popular research direction in the field of industrial applications, with the advantages of contactless operation, high degree of freedom, and great controllability. However, there are still some challenging issues that need to be resolved. First of all, more advanced circuit topologies and magnetic coupling structures need to be designed to achieve the power conversion goals of diversified applications. Second, novel control methods, optimization algorithms, and modeling methods enable systems to be better controlled and designed. Finally, potential application scenarios need to be discovered so that this novel power transfer method can be applied in more suitable applications. Therefore, this topic is organized by the responsible editor to gather the power of more scholars. With reviewers' hard work and considerations, 32 papers were finally accepted for publication in this Special Issue.

The first category focuses on the design of circuit topologies and magnetic coupling structures. The first article 1) proposes a power regulation method with the switch-controlled capacitor to lower the input current of the rectifier at the cost of a limited increase of the inverter's current stress. The second article 2) provides a secondary side static zero compensation switching method. The load characteristics based on the S-S (Series–Series) compensation type coupling system is analyzed. In order to minimize the current stresses, a parameter design method with double-sided capacitor-inductor-inductor-inductor-capacitor compensation topology is proposed in 3) to optimize the coil currents without the effect on the output fluctuation. A novel compact magnetic coupler is proposed in 4) to reduce the leakage electromagnetic field (EMF). The idea of this work is, first, adopting the compensation inductors of the LCC-LCC compensated WPT system as EMF cancelling coils and EMF alleviation can be achieved without any additional components; second, integrating the power transfer coils and the EMF cancelling coil into one magnetic coupler to compact the system. In article 5), an LCLC-LC compensated capacitive power transfer (CPT) charger is systematically analyzed to achieve these characteristics. Design principle of the CPT charger is also derived with arbitrarily given coupler and configurable charging profile, proving enough design freedom. In 6), the authors proposes a CPT system with multiple constant voltage (CV) pickups against variation of load resistance and the pickups moving in and out. First, a new equivalent circuit of the capacitive coupler is proposed by using the inverse hybrid parameters. Based on this model, an LCLC-compensated network is analyzed and designed to achieve a CV on the transmitting plates with different number of pickups.

The articles of the second category analyzed different forms of multicoil WPT systems. The first paper 7) explores the potential of relay coils (ReXs) to extend the horizontal charging area for planar inductive couplers. It focuses on the coupling mechanism and derives the equivalent coupling coefficient for model simplification. Based on the new model, a one-ReX coupler is proposed to enhance the coupling under large misalignment. An evaluation method based on black-box Z-parameter two-port model is proposed in 8) for the wireless power-relay system. This method can easily obtain the theoretical optimal efficiency and corresponding load from black-box measurement instead of acquiring all the parameters of the resonant coils. An optimal design for mid-range WPT system based on multiple repeaters is proposed in 9), which aims at powering high voltage side sense module in HVdc applications. To further optimize the system, the optimized spaced structure with different distances is investigated, which can improve transferring efficiency under same distance requirement. A multiload WPT system combining the parity-time (PT) symmetry principle and time-sharing control strategy is proposed in 10). Each load can maintain constant output power with constant transfer efficiency about 90% in a wide coupling range, and realize power distribution at desired values simultaneously. A 4 kV/120 A solid-state DC circuit breaker (DCCB) based on discrete SiC MOSFETs is introduced in 11). The DCCB is designed in a five-layer tower structure. Each layer consists of a circular main conduction branch and an attached gate driver. There are two primary benefits in the proposed DCCB. First, it reduces conduction loss with multiple devices in parallel. Second, it achieves an ultrafast response speed with SiC MOSFETs. In 12), the authors present an Inductive Power Transfer (IPT) system with dual secondary loops, which only needs a single inverter and can automatically control the Txs by its circuitry reflective property. The system can enhance the transmitting current when Rx couples with Tx, and weaken that when Rx does not couple with Tx. A receiver position estimation method suitable for multitransmitter (multi-TX) WPT systems from a new perspective of machine learning is proposed in 13). The novel method uses the voltage and current of the transmitter side, and is realized through self-learning, which can solve the problems of complex electromagnetic environment and slow response in the traditional method.

The articles in the third category mainly deal with the applications of control methods, model construction, and algorithms in IPT systems. A new bidirectional wireless power transfer topology that facilitates WPT in both directions using fewer components is proposed in 14) for wirelessly powered consumer applications. In 15), an energy transfer control method based on the estimation of the load and mutual inductance of the segmented dynamic wireless power transfer (DWPT) system is proposed. The relation between the load and the reflected impedance of the primary side is studied, and the parameters of the secondary-side LCC network are tuned to avoid the two solution problems in the estimation of the load. Based on the results of estimation, a two-case controlling strategy is proposed to switch between power-on station and detection

Digital Object Identifier 10.1109/TIA.2021.3126705

station of the DWPT system according the target of energy transferring. A μ-controller based on the structured singular value with regard to the uncertainty of multiple parameter perturbations and external disturbances of IPT systems to achieve constant current charging is proposed in 16). By using a boost converter as an impedance compensation network, the IPT system can obtain the maximum power transfer efficiency when the charging starts. However, the charging current varies under the load and frequency perturbation during the charging process. A new implementation of a PT-symmetric circuit using a combination of self-oscillating methods and pulsewidth modulation (SO-PWM) is presented in 17). The self-oscillating mode is activated in the strong coupling region, which guarantees a constant output power and constant transfer efficiency against the coupling coefficient variation. In 18), a practical method for optimizing aluminum shielding structure S-parameters is proposed to maximize the efficiency of IPT system, taking iron losses in steel part and aluminum shielding into account. The LCC-LCC compensation is widely used in the IPT systems. However, there is no simple and accurate small-signal equivalent circuit model for this resonant converter. Based on the extended describing function method, the authors of 19) propose a full-order (17th-order) equivalent circuit model to accurately predict the small-signal behaviors. In 20), the authors present a design method for DWPT system based on automated guided vehicle, and take into account W-type structure of noncontact transformer optimization. Moreover, through the combination of finite element method and sensitivity analysis based on Latin hypercube sampling, a high-precision response surface is established, and the noncontact transformer is multiobjective optimized through particle swarm optimization algorithm. Paper 21) presents a secondary side voltage and current estimation method in the WPT systems on the basis of the load parameter identification. Compared with the conventional methods, joint estimation of several secondary side voltages and currents is achieved in this article to monitor WPT electrical stress, based on only the rms value of one primary side measured voltage. In 22), the authors propose receiver position identification (RPI) method based on magnetic integration compensation inductance, using the voltage and current of the magnetic integration compensation inductance, and the transmitter current. Compared with the conventional methods, the proposed method does not add additional detection coils and position sensors, and RPI is realized based on electric parameters of the primary magnetic integration compensation inductance and transmitter. In 23), the optimization processes of the coupling mechanism are presented in detail. First, they illustrate the great superiority of unequally spaced Tx coil, compared with traditional uniformly spaced one. Then, a genetic algorithm (GA) to optimize the side lengths of the Tx coils is highlighted by discussing the main design considerations and methods in a comprehensive manner. Furthermore, the Rx coil with varying radius size per turn is proposed in terms of the distribution of magnetic field generated by the optimized Tx coil.

The fourth category concerns with specific applications under different scenarios. In 24), the authors introduce a tripolar plane-type (TPT) transmitter enabling three-dimensional (3-D) omnidirectional WPT for consumer electronics, such as mobile phones and tablet computers. The proposed TPT transmitter is a 2-D plan-type structure, but it shows a 3-D omnidirectional power transmitting capability. This structure consists of two crossed bipolar coils and a unipolar circular coil, and the three coils are mutually decoupled naturally. An omnidirectional WPT system for powering up electronic devices inside a tubular structure is proposed in 25), which has good received voltage stability no matter how the receiving coil self-rotates on its own axis or revolves around the z-axis. Paper 26) proposes an extremum seeking algorithm based on square wave, which provides an alternative method to the dynamic maximum power transmission problem of the 3-D WPT system. By simultaneously detecting two azimuths of the 3-D WPT system, the detection time of the maximum power transmission point is reduced. In order to extend cruising range, the authors in 27) developed a uniform power IPT system for autonomous underwater vehicle (AUV). A novel magnetic coupler with a low output fluctuation, low weight of receiver, and a low space occupation of the AUV is proposed in this article. In 28), a novel hybrid transmitter composed of conical and planar spiral coils is proposed that greatly improves the misalignment tolerance and transfer performance. In 29), a multiload WPT system is proposed for the power supply of AUV cluster system. The segmented arc solenoid transmitter coil is designed to generate the concentrated magnetic field. The adjacent transmitter coils are reversely wound to form the strengthened magnetic field, which can improve the coupling between the transmitter and the receiver. In 30), an arc-shaped underwater WPT magnetic coupler is proposed, which is suitable for AUV's curved shell. Especially, the proposed novel magnetic coupler utilizes Fe-based nanocrystalline alloy soft magnetic material as the magnetic core. Both volume and weight of the receiver are reduced compared with the traditional Mn-Zn ferrite material. Ppaer 31) analyzes the generalized PT symmetry conditions of four basic WPT topologies based on circuit theory and coupled mode theory. According to this unique characteristic, a constant-voltage WPT system for spinal cord stimulation is designed, which is independent of the transfer distance and load in a wide range. Finally, in 32), the authors provided a current state of the art review of all available designs for detecting metal and living objects in WPT systems. Working principles and qualitative comparisons in terms of sensitivity, accuracy, and cost of major detection methods are presented to reveal their inherent limitations and available applications.

The Guest Editors sincerely hope that the research topics covered in this Special issue can pave the way for new ideas and solutions to promote more in-depth research and wider application of WPT technology.

Acknowledgment

This special issue would not be possible without outstanding support from the associate editors and all the reviewers. The Guest Editorial Board would like to thank them for the support. The Guest Associate Editors for this special issue are as follows.

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The Guest Editorial Board would also like to thank the board of IEEE Industry Application Society for their sponsorship; Dr. T. Nondahl, Dr. M. Mitolo, and Dr. P. Wung for established the timeline and continue suggestions and technical support for the review process.

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RELATED WORKS

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