Low-Frequency-Switching High-Frequency-Resonating Wireless Power Transfer

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I. INTRODUCTION

Emerging wireless power transfer (WPT), as one of most epoch-making technologies, has been extensively investigating and gradually applied in various industrial applications and interdisciplinary areas because of its advantages of better safety and convenience, stronger reliability and electrical isolation, and lower maintenance. Due to the high efficiency and high-power capability, the mechanism of magnetic resonant coupling was identified as a significant promotion on current WPT techniques. However, the high-frequency-resonating (HFR) WPT systems usually require an inverter to operate at high-frequency switching (HFS) for maintaining high-efficiency transmission. To reduce the switching frequency, a low-frequency-switching (LFS) energy injection scheme was studied in a 1-MHz HFR-WPT system based on a Class-E converter [1], but it inevitably involves high output fluctuations. Besides, a harmonic charging scheme was revealed that the harmonic WPT causes a higher switch conduction loss [2]. Another harmonic WPT scheme using the MOSFETs [3] with bidirectional conductivity has verified the power loss reduction, but it still suffers from large circulating currents and amplitude fluctuations, thus increasing the conduction loss. Although the phase-shift control (PSC) [4] is widely used for power control in various WPT applications due to its briefness and effectiveness, the need of high-performance switches and the power losses with the HFS will raise new challenges. To suppress the amplitude fluctuations and power losses while maintaining the power controllability, a multi-topological LFS-PSC will be proposed and implemented in this paper. It can significantly alleviate those rigorous requirements on current switches for the realization of HFR-WPT applications while with insignificant fluctuations.

II. METHODOLOGY

The proposed LFS-PSC WPT system is depicted in Fig. 1(a), where the LFS-HFR operation can be directly achieved based on a full-bridge or half-bridge inverter with good applicability. According to the practical requirements and load characteristics, the proposed system can be correspondingly configured as two basic WPT topologies – series-series (SS) and series-parallel (SP) configurations which can be flexibly extended to incorporate with other complex compensation networks. The frequency-division factor n_{sw} can be chosen as needed to generate a low-frequency sine wave, and the low-frequency square-wave gate signals are subsequently offered for switches via a zero-crossing comparison. In Fig. 1(b), the principle of proposed LFS-PSC is presented to energize the WPT and realize the power control by flexibly regulating the LFS phase-shift angle. Also, a unified PSC law can be formed for all the PSC-controlled WPT systems with an equivalent phase-shift angle. The proposed LFS-PSC WPT system takes the key merits of switching frequency reduction, switching loss suppression and thus system efficiency improvement while maintaining the power controllability. Hence, the proposed LFS-PSC scheme is promising and particularly attractive for superseding the equal-power HFS-PSC WPT systems, thus getting rid of the stringent requirements on high-performance switches.

Under the LFS-PSC, the transmitter fluctuation ratio κ_i of the SS-WPT and the SP-WPT are evaluated versus the coupling coefficient k with various n_{sw} and loads R_{L} in Fig. 2(a) and 2(b), respectively. The lower transmitter fluctuation can be obtained with a lower coupling coefficient, which will greatly benefit the general WPT systems usually operating at the weak coupling regime. For system optimization, such fluctuations can be lowered with a larger load under the SS-WPT, while they can be reduced with a smaller load under the SP-WPT. Fig. 2(c) and 2(d) show the system efficiencies of the SS-WPT and the SP-WPT under the HFS-PSC and the proposed LFS-PSC, respectively. The ideal HFS-PSC works without dead zones. With the same power level, the system efficiencies under the LFS-PSC can fall in between those under the HFS-PSC with and without dead zones, successfully improved by 3.78% and 3.63%. These beneficial characteristics well confirm that the proposed multi-topological LFS-PSC technology can effectively suppress the switching and conduction losses, and mitigate the negative effects of dead zones, thus improving the system efficiency. Finally, an experimental prototype has been constructed and tested to further verify the feasibility of proposed multi-topological HFR-WPT using the LFS-PSC. More experimental results will be given in the full paper.

III. CONCLUSION

A multi-topological HFR-WPT using the LFS-PSC has been proposed and implemented for high-efficiency HFR-WPT applications. The proposed LFS-PSC is newly used to control the HFR wireless power and improve the system efficiency. It can readily suppress the switching frequency and mitigate the adverse impacts of dead zones on power and efficiency losses. By optimizing system design, both the current fluctuations and switch losses can be effectively reduced. Theoretical analysis, numerical simulation and experimental results will be given to verify the feasibility of proposed LFS-PSC WPT system. This work was supported by a grant (Project No. 17204317) from the Hong Kong Research Grants Council, Hong Kong Special Administrative Region, China.

References

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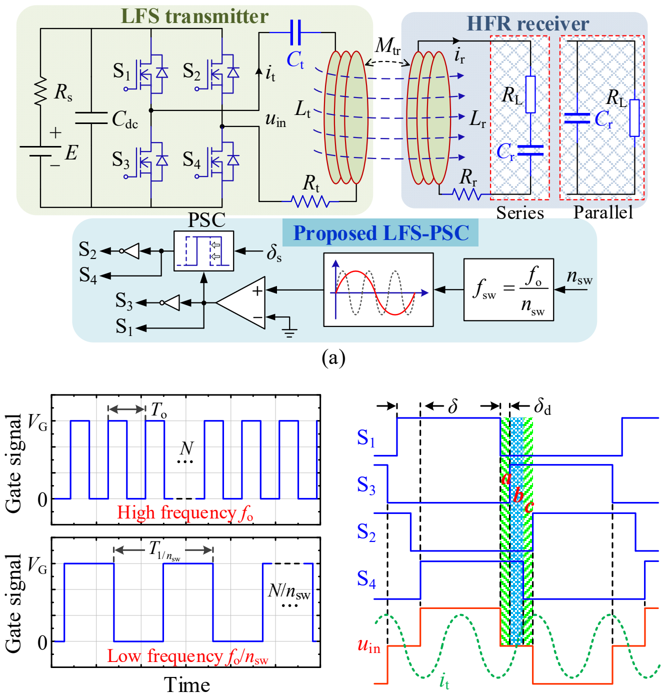
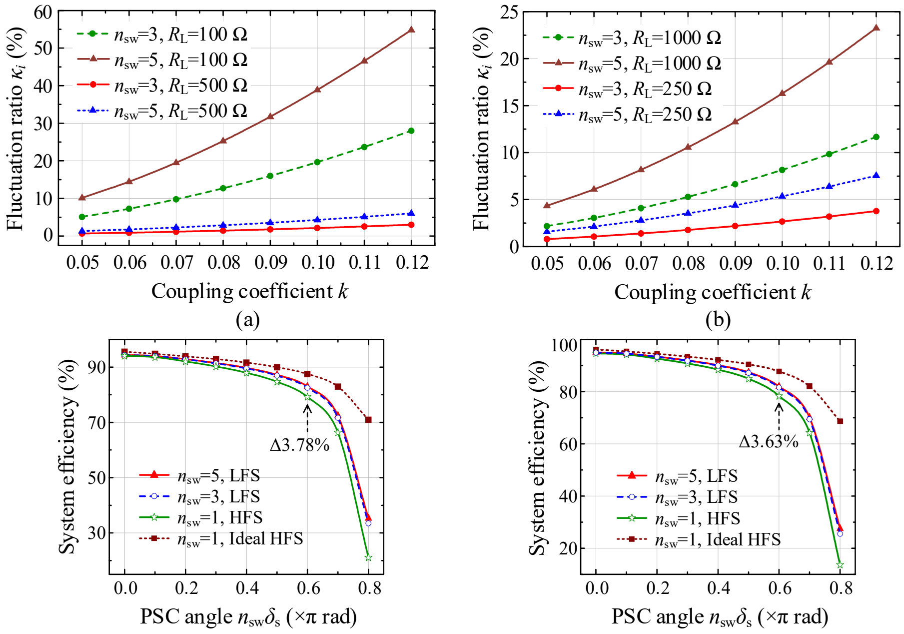


(a)

(b)

Fig. 1. Proposed LFS-PSC WPT system with SS/SP topology. (a) Topologies. (b) Principle of the LFS-PSC.



(a)

(b)

(c)

(d)

Fig. 2. System characteristics of proposed LFS-PSC WPT systems. (a) Fluctuations (SS-WPT). (b) Fluctuations (SP-WPT). (c) Efficiencies (SS-WPT). (d) Efficiencies (SP-WPT).