A Switched-capacitorless Energy-encrypted Transmitter for Roadway-charging Electric Vehicles

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I. Introduction

Due to cleanliness, convenience and high efficiency, wireless power transfer (WPT) technology has been extensively and deeply investigated. In recent years, energy encryption has drawn researchers' attention to satisfy practical requirements of security and reliability in the theme of intelligent transportation and smart city. Especially for roadway-charging electric vehicles (EVs), the use of energy encryption can guarantee the transmitted energy being effectively harvested by the authorized receptors instead of being secretly stolen by the unauthorized ones. Recently, a chaotic encryption strategy based on switched capacitor arrays has been proposed to realize energy security in WPT systems [1, 2]. However, because of the need of discretely adjusting the resonant capacitance and hence the operating frequency, this encryption scheme suffers from the drawbacks of limited energy-transferred channels, high voltage stress across switches and relatively low flexibility. In addition, a generic encryption model based on certificate-less cryptography has been developed to improve the energy security performance for WPT systems [3], but its computational complexity and time involved seriously restrain from dynamically encrypting the operating frequency. Meanwhile, a traditional series-to-series (SS) topology with fixed values of resonant inductance and capacitance has been identified to exhibit a selective characteristic for multiple loads when operating at the selected receptor's resonant frequency [4]. This mechanism can be newly extended to derive an energy-encrypted transmitter without using a switched-capacitor array for multiple energy receptors such as roadway-charging EVs. Consequently, in this paper, a switched-capacitorless energy-encrypted transmitter is proposed for roadway-charging EVs. Moreover, a two-dimension chaotic frequency-and-duration encryption (FDE) algorithm is proposed to improve the security performance while maintaining relatively high efficiency.

II. Methodology

The proposed FDE-WPT system without using a switched-capacitor array in the transmitter is shown in Fig. 1(a). The switched-capacitorless transmitter is firstly introduced to the energy-encrypted WPT system, which can offer the definite merit of continuously and flexibly regulating the operating frequency. When the receptors in the *m*-th channel are authorized, no matter the transmitter operates at resonance or not, the corresponding efficiency can be derived out. It indicates that the primary coil inductance and the matched resonant capacitance have no influence on its operating efficiency. Although the primary coil internal resistance leads to extra power loss, because of the enhanced mutual inductance by the ferromagnetic spokes as shown in Fig. 1(b), the power loss in the primary coil can be effectively suppressed and even insignificant. Thus, the proposed system takes the advantage of lower transmitter's power loss over the energy-encrypted SS WPT system with switched-capacitor arrays.

Data interaction based on wireless communication facilitates the encryption and decision-making unit to achieve maximum efficiency band trace (MEBT), which provides a secure frequency band to ensure relatively high efficiency in the authorized receptor. Then, a two-dimension chaotic encryption technique is adopted to generate the encrypted frequency and its active duration sequences, namely, the security key. Furthermore, hysteresis control and high-frequency pulse modulation (HFPM) are employed to realize pulse density modulation (PDM). The output voltages of both the authorized and unauthorized receptors and the two-dimension FDE security key are shown in Fig. 2(a). Only the authorized receptor with knowledge of the security key can readily decrypt the encrypted energy, while, due to the lack of security key, the unauthorized ones fail to pick up any energy. Hence, it confirms that the proposed FDE and switched-capacitorless transmitter can effectively enforce the energy security. Additionally, the efficiency and output power versus the operating frequency are plotted in Fig. 2(b). Although the efficiency will decrease when the operating frequency is adjacent to the unauthorized receptors' resonant frequency, the proposed MEBT and FDE can dynamically generate a new sequence of secure energy-transferred channels to guarantee high-efficiency operation, always higher than 90.75%. Finally, an experimental prototype has been constructed and tested to further verify the feasibility of the proposed FDE-WPT system. More experimental results will be given in the full paper.

III. CONCLUSION

A switched-capacitorless energy-encrypted transmitter, incorporated with two-dimension FDE technology, has been proposed and implemented for roadway-charging EVs. To prevent the energy from being illegally harvested by the unauthorized receptors, the proposed two-dimension chaotic FDE technology generates a well-defended key to improve the security performance while retaining high efficiency. Theoretical analysis, numerical simulation and experimental results will be given to verify the feasibility of the proposed FDE-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.

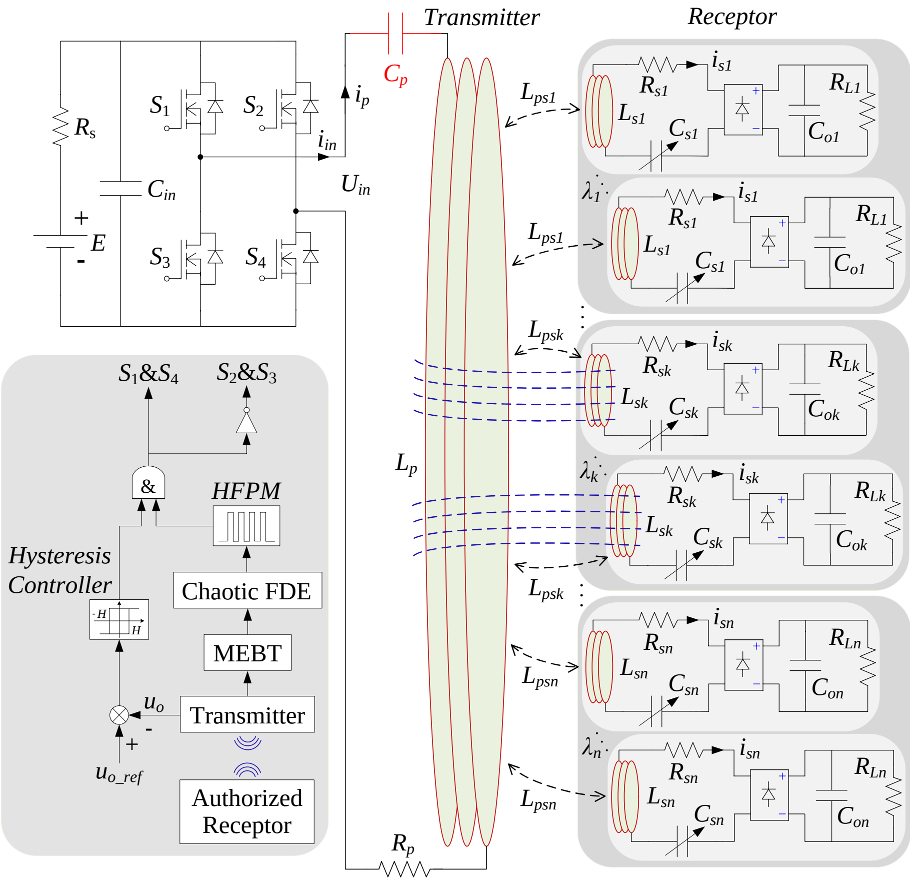
References

[1] Z. Zhang, K.T. Chau, C. Liu, C. Qiu and F. Lin, "An efficient wireless power transfer system with security considerations for electric vehicle applications," *J. Appl. Phys.*, vol. 115, no. 17, paper no. 17A328, pp. 1-3, May 2014.

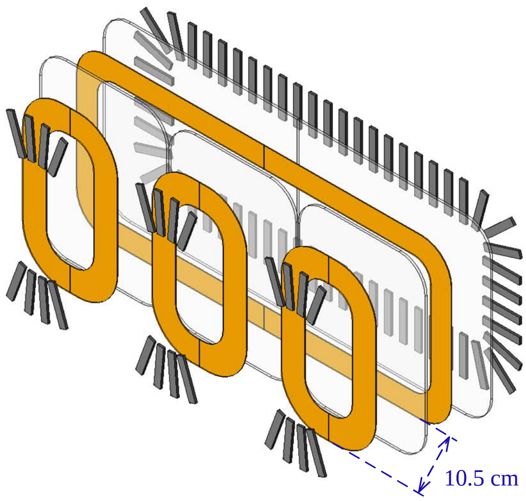
[2] Z. Zhang, K. T. Chau, C. Qiu, and C. Liu, "Energy encryption for wireless power transfer," *IEEE Trans. Power Electron.*, vol. 30, no. 9, pp. 5237-5246, Sep. 2015.

[3] E. Ahene, M. Ofori-Oduro, and B. Agyemang, "Secure energy encryption for wireless power transfer," in *Proc. IEEE Int. Advance computing Conf.*, Jan. 5-7, 2017, pp. 199-204.

[4] Y. Zhang, T. Lu, Z. Zhao, F. He, K. Chen and L. Yuan, "Selective wireless power transfer to multiple loads using receivers of different resonant frequencies," *IEEE Trans. Power Electron.*, vol. 30, no. 11, pp. 6001-6005, Nov. 2015.



(a)



(b)

Fig. 1. Proposed FDE-WPT system without using switched-capacitor array in transmitter. (a) Topology and control. (b) Geometries of primary and secondary circuits.

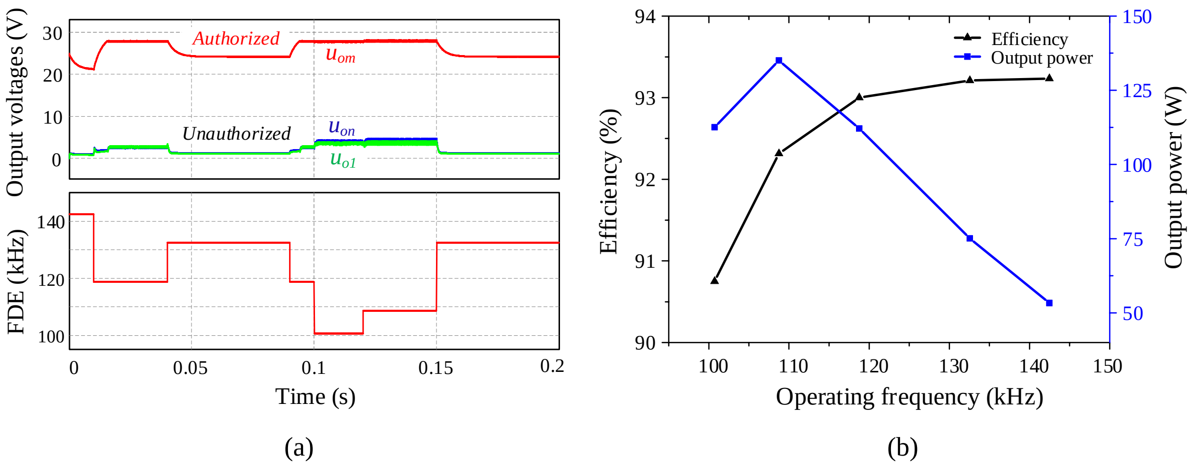


Fig. 2. Waveforms of proposed FDE-WPT system. (a) Output voltages and FDE security key. (b) Efficiency and output power.