CC 및 CV 배터리 충전 특성을 위한 재구성 가능한 토폴로지를 갖춘 하이브리드 IPT 시스템

리광야오, 사준신, 김동희†
전남대학교 전기공학과

A Hybrid IPT System with Novel Dual-Transmitter for Constant Current and Voltage Battery Charging

Guangyao Li, Junchen Xie, and Dong-Hee Kim
Department of Electrical Engineering, Chonnam National University

ABSTRACT

The proposed system can be reconfigured as S-S topology, where the "HH"-coupled coils compose channel 1 for CC feeding to the load. After reaching the rated charging voltage U_b, the inverter Q_4 turns on, which reconfigures the LCC-S topology to achieve the CV, with channel 2 being composed of the "DDH"-coupled coils. In this way, not only CC and CV of the battery can be achieved, but also the output power can be smoothed in case of door-to-door misalignment. Experimental results show that within the coverage of the transmitting side, improved efficient and stable output can be achieved.

1. INTRODUCTION

Inductive power transfer (IPT) technology enables wireless charging between systems by utilizing magnetic field coupling without requiring a physical connection. Owing to its advantages of safety, convenience, and low maintenance cost, especially the application of IPT to e-mobility for wireless charging is one of the most promising applications.

In order to improve the efficiency of the IPT system, a novel coil design is added to increase the coupling coefficient. The three-coil structure has been used to implement CC and CV charging mode [1]. However, the receiver-side compensation in [1] was complex and two additional switches were utilized. In [2], a three-coil structure was also adopted. However, the cross coupling is large, and the compensating capacitance should be changed, leading to two relays, which can increase the complexity, cost, and weight of the receiver.

This paper proposes a novel hybrid topology to enable CC and CV outputs based on the three-coil structure. An extra winding is added on the transmitter-side so that the system can be reconfigured to perform as the two-coil structure with a CC output or the three-coil structure with a CV output. In this way, a simple and low-cost solution for CC and CV outputs can be achieved. The proposed system is verified by experiment.

2. PROPOSED CC AND CV TOPOLOGIES

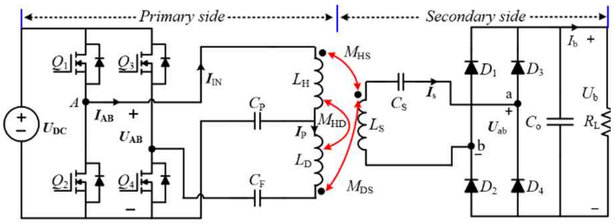

Fig. 1 Proposed hybrid and reconfigurable topologies for CC and CV charging mode.

Fig. 1 shows the proposed reconfigurable topology to realize CC and CV charging. There are two bipolar transmitting coils L_H and L_D on the transmitting side, and only the H-shaped receiving coil L_S on the receiving side to complete energy harvesting. C_P and C_S are series compensation capacitors, and C_F is a parallel compensation capacitor. I_{IN}, I_P and I_S are the currents flowing through coils L_H, L_D and L_S respectively. M_{HS}, M_{DS} and M_{HD} are mutual inductance.

The proposed topology has three resonant tanks all operating at the resonant angular frequency ω_0:

$$\omega_0 = \frac{1}{\sqrt{L_H C_P}} = \frac{1}{\sqrt{(L_D - L_H) C_F}} = \frac{1}{\sqrt{L_S C_S}} \tag{1}$$

2.1 S-S topology for CC mode

For CC mode, Q_3 and Q_4 are always off, and Q_1 and Q_2 work as a half-bridge inverter, as shown in Fig. 2. shows the equivalent circuit of the S-S topology.

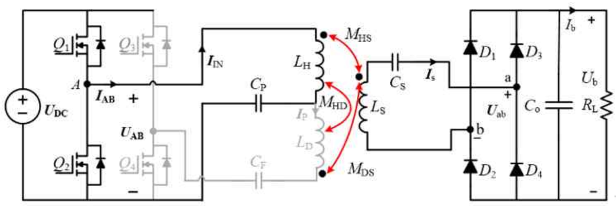

Fig. 2 Proposed S-S topology for CC mode.

Based on the Kirchhoff voltage law (KVL), the output current are:

$$I_b = \frac{4U_{DC}}{\pi^2 \omega_0 M_{HS}} \tag{2}$$

2.2 LCC-S topology for CV mode

For CV mode, switch Q_4 is always on, Q_3 is always off, and Q_1 and Q_2 work as a half-bridge inverter, as shown in Fig. 3. shows the equivalent circuit of the LCC-S topology.

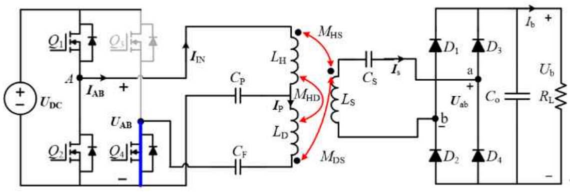

Fig. 3 Proposed LCC-S topology for CV mode.

According to the Kirchhoff voltage law, the output voltage can be calculated as follows:

$$U_b = G_{UU} U_{DC} = \frac{U_{DC} R_L}{\sqrt{\left(\frac{R_L}{\omega_0^2 C_p M_{DS}}\right)^2 + \left(\frac{\pi^2 \omega_0 M_{HS}}{2}\right)^2}} \tag{3}$$

From (3) and Fig. 4, if in the experimental design process, the compensation capacitor C_P can be reasonably designed to make the system realize CV when the load is large.

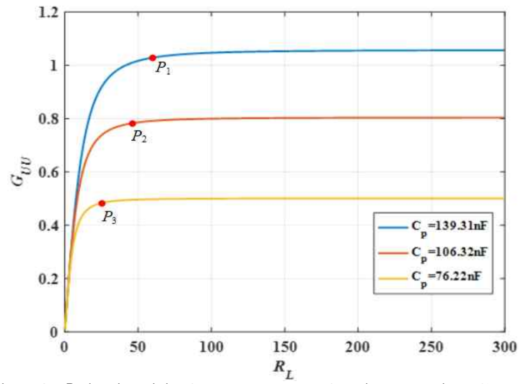

Fig. 4 Relationship between R_L and voltage gain G_{UU}.

3. EXPERIMENTAL VERIFICATION

To verify the effectiveness of the experiment, an experimental prototype was built. The essential parameters are tabulated in Tab. I.

Tab. I Essential System Parameters of the IPT System.

Symbols	Values	Symbols	Values
U_{DC}	220V	f_o	85kHz
U_b	56V	M_{HS}	10.3μH
C_P	139.31nF	C_F	42.52nF
C_S	36.64nF	L_S	101.21μH
L_D	107.6μH	L_H	25.17μH
M_{DS}	26.6μH		

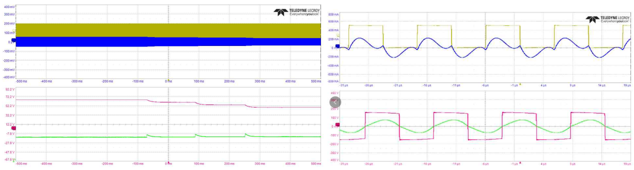

Fig. 5 Experiment waveforms of U_b, I_b, U_{AB} and I_{IN} in CC mode.

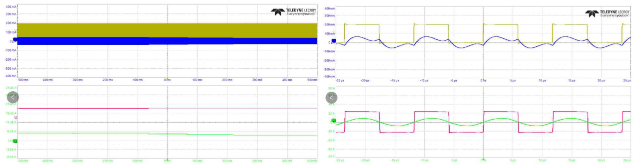

Fig. 6 Experiment waveforms of U_b, I_b, U_{AB} and I_{IN} in CV mode.

For CC output, R_L changes from 10 to 40Ω; and for CV output, R_L changes from 15 to 70 Ω. It can be seen from Fig. 5 and Fig. 6 that the designed hybrid topology compensation IPT systems can realize CC and CV charging mode. The peak efficiency of the system is 92.4%.

4. CONCLUSIONS

A novel reconfigurable topology for CC and CV outputs in a wireless charging system based on the three-coil structure has been proposed in this paper. The transmitting coil was split into two windings with one winding having a turn number much smaller than the other. The two windings were fully compensated and connected to the corresponding inverter phase. Thus, the system could shift between the two-coil structure and the three-coil structure for CC and CV output, respectively. The mathematical model has been built, and the CC and CV characteristics have been evaluated. In the proposed method, the working frequency was fixed and only one relay was utilized for the shift of CC and CV charging. A prototype was developed with 92.4% maximum efficiency. The experimental results had validated the effectiveness of the proposed system.

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참 고 문 헌

[1] Y. Chen, R. Mai, Y. Zhang, M. Li, and Z. He, “Improving misalignment tolerance for IPT system using a third-coil,” IEEE Trans. Power Electron.,vol. 34, no. 4, pp. 3009-3013, Apr. 2019.

[2] Y. Yao, Y. Wang, X. Liu, Y. Pei, and D. Xu, “A novel unsymmetri-cal coupling structure based on concentrated magnetic flux for high-misalignment IPT applications,” IEEE Trans. Power Electron., vol. 34, no. 4, pp. 3110-3123, Apr. 2019.