전기자동차의 다중충전 및 V2G 응용을 위한 새로운 통합 배터리 충전기 구조

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A Novel Integrated Battery Charger Structure for Multiple Charge and V2G application for Electric Vehicles

ABSTRACT

This paper has introduces a novel Integrated On-board Charger (IOBC) to reduce the size, weight and cost of power conversion stages in Electric Vehicles (EVs). The IOBC is composed of an OBC and a low voltage dc-dc converter (LDC). The IOBC includes a bidirectional ac-dc converter and a bidirectional full-bridge converter with an active clamp circuit. The LDC converter is a hybrid topology combining an active clamped full-bridge converter and a forward converter derived from the Weinburg converter topology. Unlike conventional OBC, the proposed IOBC is compact and the LDC converter of it can achieve a higher efficiency. In addition, the LDC converter of the proposed IOBC can achieve high step-down voltage conversion ratio, no circulating current, no reverse recovery current of the rectifier diodes and small ripple current of output inductor on the auxiliary battery. A 1kW hardware of the LDC converter is implemented to verify the performances of the proposed IOBC.

Index Terms – Integrated OBC; LDC converter; Hybrid converter, Weinburg converter.

1. Introduction

The energy storage system in Electric vehicles (EVs) and plug-in hybrid electric vehicles (PHEVs) normally consist of two kinds of batteries (low voltage battery, 12V or 24V and high voltage battery, 400V). One is the propulsion battery, which provides high dc voltage for the electric motor. The other is the auxiliary battery, which supplies low dc voltage for electric fields such as lighting, entertainments, signaling circuits, and stereo sound system. To charge for these two batteries, two converters are required: on-board charger (OBC) charging the propulsion battery and LDC converter charging the auxiliary battery. In current dc-dc converters system on EVs or PHEVs, these two converters exists separately, thereby increasing the size and the cost of power conversion system.

IOBC structure has been introduced recently and it combines an OBC and an LDC converter to reduce the size, weight, cost and the rating of the devices. An IOBC can carry out three functions: 1) Charge from grid-to-vehicle (G2V); 2) Discharge from vehicle-to-gird (V2G); 3) Propulsion-to-auxiliary (P2A) as shown in Fig 1. One problem of the integrated OBC converter is that the LDC converter integrated in OBC ca hardly show the as good performance as a separated one. In case of the one in [2], the lower efficiency is attributed to the high conduction loss. The conduction loss is caused by the two stage power conversion. In [3], an IOBC converter was presented based on Voltage/Current-Fed Full-bridge structure. The circulating current can be minimized and soft-switching can be guaranteed for a wide range of load. Based on experimental results, the converter in [3] exhibits a simpler structure and a higher efficiency compared to the converter in [2]. Nevertheless, when the power is delivered from propulsion battery to auxiliary battery, it works like a current-fed converter with an input inductor. This inductor leads to an increase in voltage of transformer, therefore, a high step-down turns-ratio is required. In additions, rectifier diodes suffer from reverse recovery current which results in a lower performance in high current application.

In this paper a novel IOBC is proposed as shown in Fig. 1. In the proposed topology a novel LDC converter is proposed to solve the problem of high step-down turns-ratio of the transformer in [3]. The proposed LDC converter is a hybrid converter between a PSFB converter and a forward converter. The inductor L_{o1} is used to deliver the energy during the freewheeling interval of the PSFB converter, as shown in Fig. 2. The full ZVS operation of secondary switches can be achieved by the magnetizing current of the transformer and ZCS of leading leg can be obtained all over the operating condition. The circulating current and reverse recovery current of the diodes are eliminated due to the output capacitor of the forward converter.

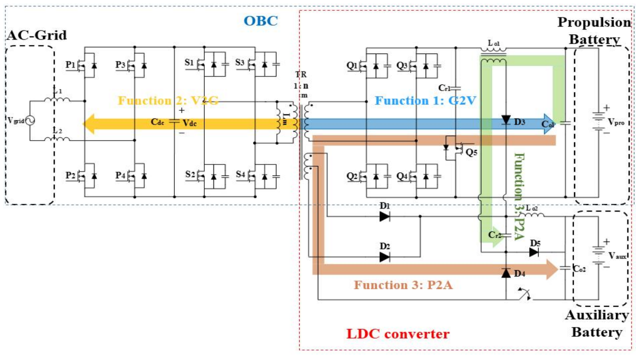

Fig. 1. The proposed integrated on-board charger

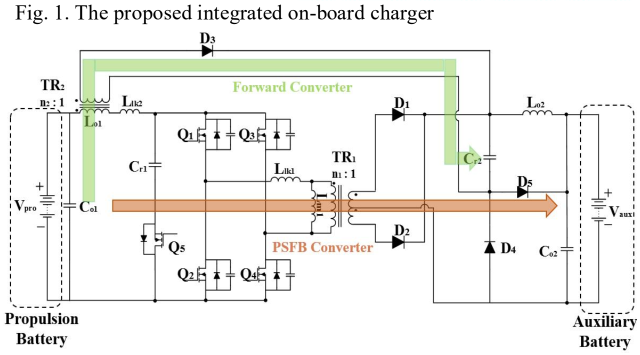

Fig. 2. LDC converter of the proposed integrated on-board charger

2. Operating principle of the LDC converter

Fig. 2 shows circuit diagram of the proposed LDC converter.

Mode $1(t_0 - t_1)$: The switches Q_1 is turned on with ZVS condition at t = t_0. The power is transferred to the output through both PSFB converter and forward converter.

Mode $2(t_1 - t_2)$: At t = t_1 the switch at Q_4 is turned-off to end the transferring power mode and move on the freewheeling mode.

Mode 3($t_2 - t_3$): The switches Q_3 and Q_5 are turned on with ZVS condition at t=t_2. The transformer TR_2 is reset by the active clamp switch Q_5.

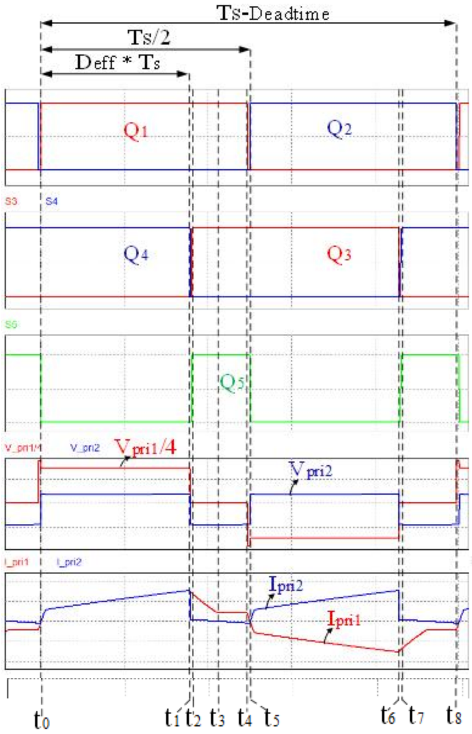

Fig. 3. Key waveforms of the proposed converter

Mode 4($t_3 - t_4$): In the primary side of the PSFB converter, the primary current $i_{pri1}(t)$ is equal to magnetizing current of the TR_1 because there is no reflected current from the output inductor.

Mode 5($t_4 - t_8$): The operations of the proposed converter in the period from t_4 to t_8 are same as the operations in the period from t_0 to t_4.

3. Experimental results

The specification of the proposed IOBC can be found in the Table 1.

TABLE 1
SPECIFICATION OF THE PROPOSED IOBC

Stages	Parameters	Value
Function I (OBC): DC-Link to propulsion battery	DC-link voltage	380 – 420 [V]
	Propulsion battery voltage	250 – 420 [V]
	Rated power	3.3 [kW]
	Efficiency (max/normal)	98.1/97.7 [%]
Function II (OBC): Propulsion battery to DC-Link	DC-link voltage	380 – 420 [V]
	Propulsion battery voltage	250 – 420 [V]
	Rated power	3.3 [kW]
	Efficiency (max/normal)	98.1/97.7 [%]
Function III (LDC): Propulsion battery to auxiliary battery	Propulsion battery voltage	250 – 420 [V]
	Auxiliary battery voltage	23 – 25 [V]
	Rated power	1 [kW]
	Efficiency (max/normal)	96/95.5 [%]

The experimental results of function I and function II are referred from the paper [1].

Fig.4 shows waveform of the lagging switch Q_1 at light load condition of 10% and Fig.5 shows the waveform of the lagging switch Q_1 at heavy load condition. The ZVS turn-on and nearly ZCS turn-off of the switch Q_1 are proved in both Fig.4 and Fig.5.

The waveform of the leading switch Q_3 is shown in Fig. 6 with ZVS turn-on condition. Fig.7 is the waveform of the primary side transformer TR_1. It can be seen that there is no circulating current in the freewheeling interval. The waveform of the primary side transformer TR_2 is illustrated in Fig. 8.

In the secondary side of the proposed LDC converter, measured waveform of the diodes D_1 is shown in Fig. 9 with no reverse recovery current. Fig. 10 shows the waveform of the diode D_3 achieving ZCS turn-on and no reverse recovery current.

The efficiency of the proposed LDC converter is shown in Fig. 11 with a wide voltage range of the propulsion battery. The maximum of 96% was achieved in the proposed LDC converter at 500W.

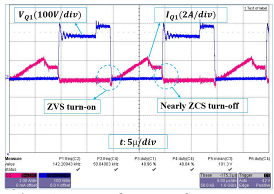

Fig. 4 Waveforms of Q_1 at 10% of the load

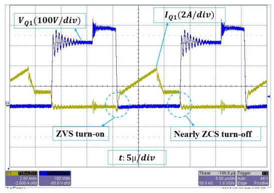

Fig. 5 Waveforms of Q_1 at heavy load condition

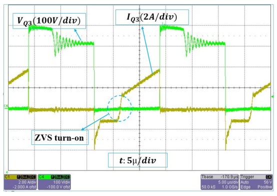

Fig. 6. Waveforms of Q_3

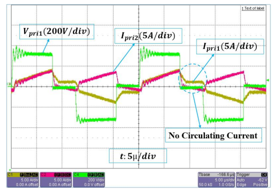

Fig. 7. Waveforms of TR_1

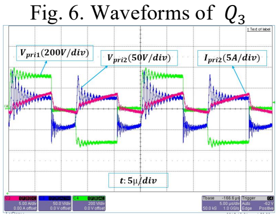

Fig. 8. Waveforms of TR_2

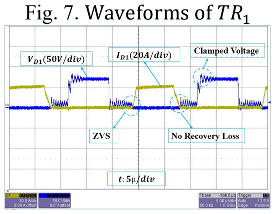

Fig. 9. Waveforms of D_1

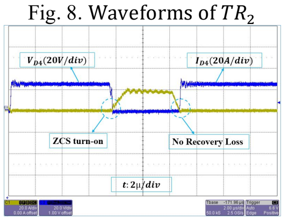

Fig. 10. Waveforms of D_3

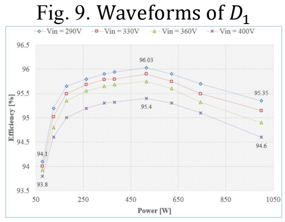

Fig. 11. Efficiency plots

4. Conclusion

This paper has introduced a novel integrated battery charger structure for multiple battery charger to reduce the size, weight and cost of dc-dc converters in EVs. The operating principle of the proposed IOBC has been describe d and its superior performance has been proved by the experimental results. The LDC converter derived from the Weinburg converter topology help increase the voltage step-down conversion ratio and achieve the high efficiency. It is expected that the proposed topology will contribute to the reduction in volume, weight and cost of the power conversion system in electric vehicle system.

References

[1] Van-Tuan Doan, Woojin Choi "A bidirectional Hybrid Switching Full-Bridge Converter with Active Clamp Circuit for V2G Application," in KIPE Summer, July. 20169, pp. 335–336.

[2] K. Seonghye and K. Feel-Soon, "Multifunctional Onboard Battery Charger for Plug-in Electric Vehicles," Industrial Electronics, IEEE Transactions on, vol. 62, pp. 3460-3472, 2015.

[3] K. Yun-Sung, O. Chang-Yeol, S. Won-Yong, L. Byoung-Kuk, and P. Gwi-Chul, "Optimal design and control of OBC-LDC integrated power unit for electric vehicles," in Applied Power Electronics Conference and Exposition (APEC), 2014 Twenty-Ninth Annual IEEE, 2014, pp. 3192-3198.