9.1kW/L, 6.1kW, 800V-48V-12V 양방향 LDC

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9.1kW/L, 6.1kW, 800V-48V-12V bidirectional LDC

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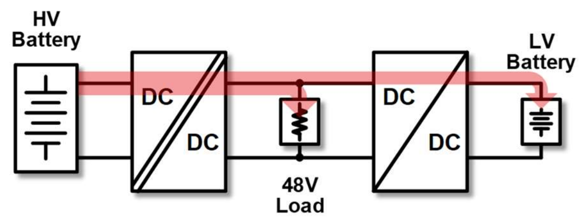
ABSTRACT

This paper proposes a new bidirectional three-port DC-DC converter (TPC) that combines an isolated dual active bridge converter and a non-isolated dual floating boost converter. This topology enables single-conversion power transfer from a high voltage (HV) battery to a low voltage (LV) battery, thereby increasing the efficiency of the converter. As a result, the proposed converter demonstrates an efficiency improvement of up to 3.2%. To validate the theoretical claims, a prototype of 6.1kW, 140kHz, 800V - 48V - 12V three-port converter has been built. The prototype achieved 97.4% of peak efficiency and 9.1kW/L of power density.

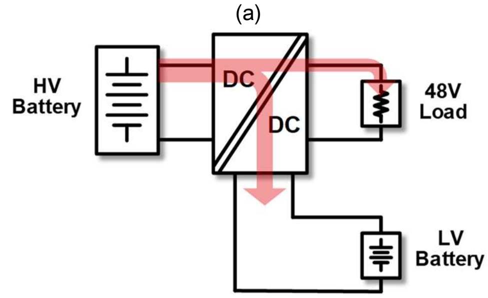
1. Introduction

The isolated DC-DC converter is widely used in many applications such as energy storage systems (ESS), data centers, electrical vehicles (EV),… In EV application, an isolated DC-DC converter is used for an on-board charger (OBC) [1] and low voltage DC-DC converter (LDC) [2]. LDC provides power for 12V loads such as headlamps, audio, radar, camera, etc…and charges a 12V battery. Due to the room limitation in the vehicles, the LDC requires a very high power density [2].

To this day, the power of 12V load in EV is gradually increasing, due to autonomous systems and entertainment systems. Therefore, the increased 12V LDC power significantly increases the maximum output current (>500A at 6kW). Consequently, high conduction loss reduces efficiency and requires large wires is costly. In order to reduce the harness with large output current, a dual low voltage system is introduced such as 48V and 12V, as shown in Fig. 1. For two low voltage systems, two converters are required. The power transfer from the HV battery to the LV battery through two converters (two stages) reduces the efficiency, as shown in Fig. 1(a). To increase the efficiency and reduce the cost and volume, a three-port converter is proposed in this paper, as shown in Fig. 1(b).



(a)



(b)

Fig.1 Low voltage system with multiple voltage: (a) with separated power converter, (b) with three-port converter.

2. Proposed three-port topology

Fig. 2(a) shows the conventional multiple converters for dual low-voltage systems, including an isolated dual active bridge converter and a non-isolated interleaved buck-boost converter. For the power transfer from the HV battery to the 48V load, the power is directly transferred through a single converter. However, transferring power from the HV battery to the LV battery necessitates passage through two converters (referred to as two stages). Consequently, two stage structure has not good efficiency. In order to improve the efficiency, three-port converter is introduced. This enables both power transfer from the HV battery to the 48V load and to the LV battery through a

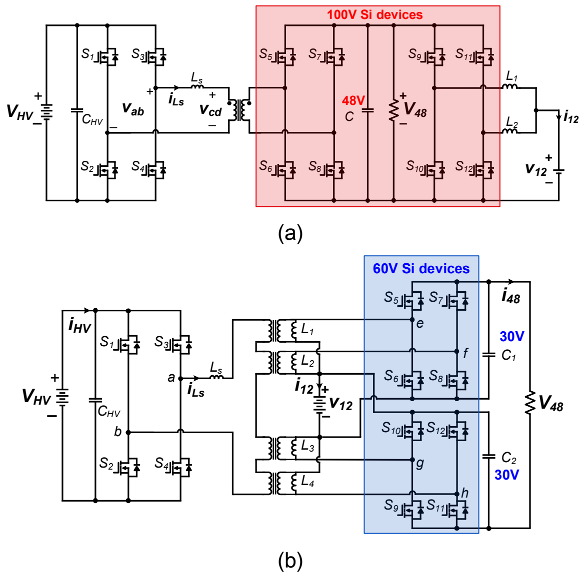


Fig. 2. Power conversions for dual low voltage systems (a) Conventional two stage structure. (b) Proposed single stage structure.

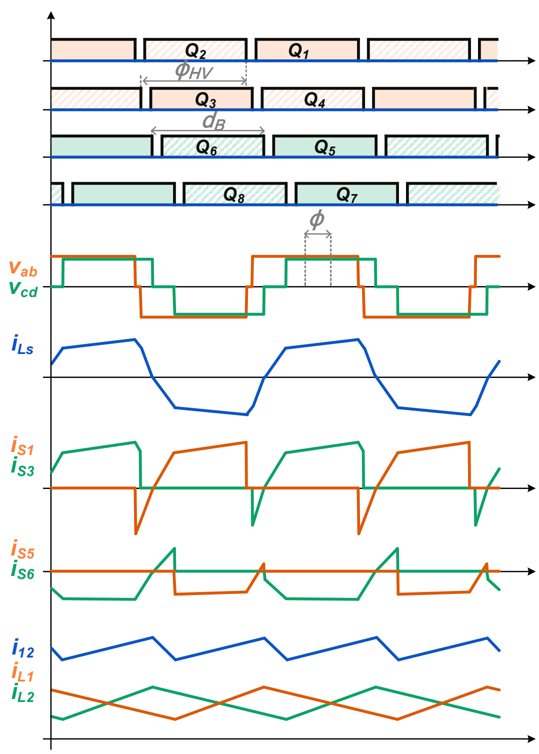


Fig.3. Key waveforms of the proposed three-port topology.

single conversion. In Fig. 2(b), a new three-port converter is proposed for dual low voltage systems. By using proposed topology, the voltage stress on the LV side is reduced, enabling the use of low voltage rating devices (from 100V Si devices to 60V Si devices). As a result, lower conduction loss due to lower $R_{DS,on}$ devices could be used and lower switching loss due to lower applied voltage.

The key waveforms operation is shown in Fig. 3. The proposed converter uses three control variables, including buck duty (d_B) for controlling voltage ratio between 48V-port and 12V-port, phase shift between the HV side and the LV side (ϕ) for adjusting power transfer from HV-port, and HV side phase shift (ϕ_{HV}) for achieving ZVS under a wide HV side voltage range. Due to the symmetrical topology, switch current waveforms are shown only S_1, S_3, S_5, and S_6. It is obvious that all switches can achieve ZVS in Fig.3. In order to verify the performance of the proposed topology, an efficiency comparison is made, as shown in Fig. 4. It can be seen that the efficiency of the proposed topology is improved. In the operation case under V_{HV} = 400V, V_{48} = 48V, and V_{12} = 14V, efficiency significantly improves by 3.2%. The loss breakdown comparison was made under V_{HV} = 620V, V_{48} = 48V, and V_{12} = 14V, as shown in Fig. 5. It can be seen that the LV conduction loss and switching loss is significantly reduced.

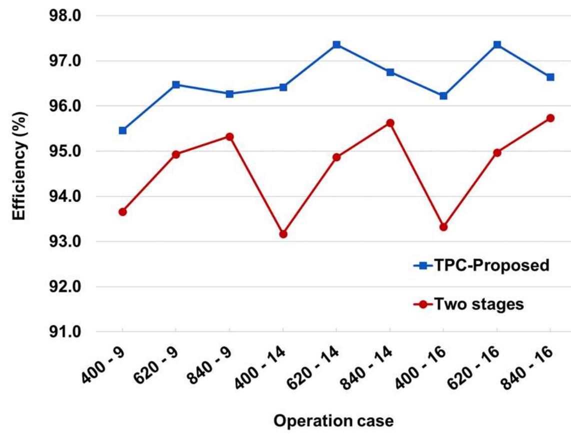


Fig.4. Efficiency comparison of the conventional and proposed topology.

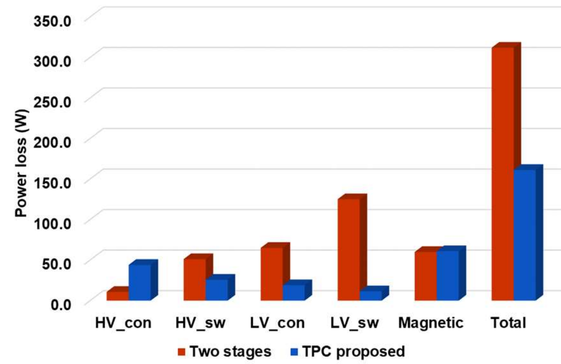


Fig.5. Loss breakdown comparison at V_{HV} = 620V, V_{48} = 48V, and V_{12} = 14V.

3. Experimental results

Fig. 6 shows a 6.1kW proposed converter built to verify the

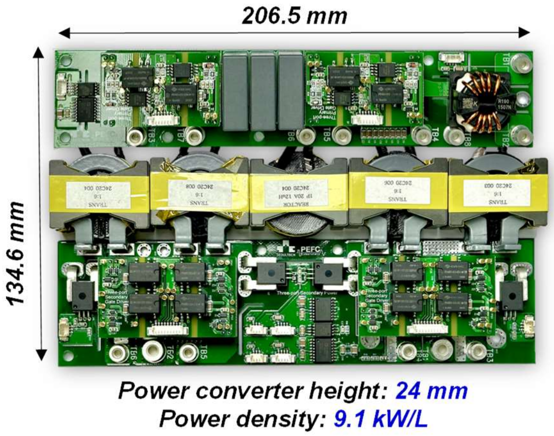


Fig.6. 6.1kW, 140kHz prototype of the proposed topology

theoretical claims and achieved 9.1kW/L of power density. The prototype utilizes the AIMCQ120R030M1T switch on the primary side and the IAUTN06S5N008T switch on the secondary side, both of which are the sample switches provided by Infineon. The converter can operate under a wide voltage range: V_{HV} = 400V-840V, V_{48} = 48V, and V_{12} = 16V. In Fig. 7, the experimental waveforms show that all switches can achieve ZVS under a wide voltage range.

4. Conclusions

In this paper, a three-port current fed dual floating current fed DAB has been proposed. With the proposed topology, the voltage stress on LV side switches is reduced. As a result, the conduction loss is reduced by using smaller $R_{ds,on}$ devices and the switching loss is reduced by smaller applied voltage. A 6.1kW, 140kHz, 800V-48V-12V prototype of the proposed TPC has been built to validate the effectiveness of the performance and the theoretical claims. The experiment results show the operating waveform under a wide input voltage range (V_{HV} = 400V - 840V) verifying that all switches can achieve ZVS turns. The prototype achieves a high power density of 9.1kW/L.

본 과제(결과물)은 교육부와 한국연구재단의 재원으로 지원을 받아 수행된 3단계 산학연협력 선도대학 육성사업(LINC 3.0)의 연구 결과입니다.
이 논문은 Infineon의 전력스위치 지원을 받아 수행된 연구임.

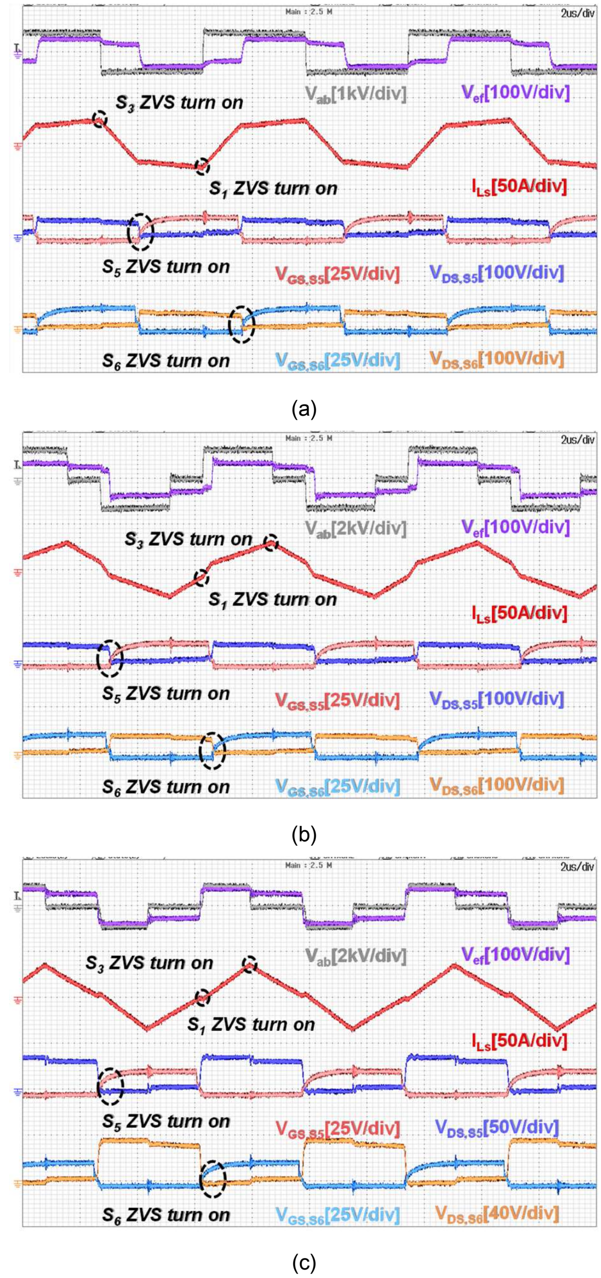


Fig.7. Experiment results at V48 =48V,V12 = 16V, PHV = 6.1kW, P48 = 4kW, and P12 = 2.1kW conditions with (a) VHV = 400V, (b) VHV = 620V, (c) VHV = 840V.

References

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[2] H. -P. Kieu, D. B. -H. Nguyen, D. Lee and S. Choi, "All-in-one Magnetic Structure for PSFB converter with Current Doubler Rectifier," 2024 IEEE Applied Power Electronics Conference and Exposition (APEC), Long Beach, CA, USA, 2024, pp. 875-880, doi: 10.1109/APEC48139.2024.10509124.