Current doubler 정류기를 갖는 LDC용 일체형 자성체 구조

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All-in-one Magnetic Structure for LDC with Current Doubler Rectifier

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ABSTRACT

This paper proposes a new magnetic that integrates leakage inductor, two filter inductors, and transformer into single planar core for isolated converter with current doubler. This integration reduces the number of core required, as well as volume, and magnetic loss, leading to a significant reduction in cost and increased efficiency. The proposed magnetic is possible for use in variable topologies. As a representative example, a phase shift full bridge (PSFB) with the proposed magnetic core is presented. A comparison between conventional separated and proposed integrated cores demonstrates that total volume and power loss of the integrated core compared to the separated core is reduced by 17% and 26%, respectively. A prototype of 3kW, 200kHz, 800V-12V converter achieved 95.5% of peak efficiency and 8.4kW/L of power density.

1. Introduction

The low voltage DC-DC converter (LDC) is one of main electrical components in electrical vehicles, supplying power to 14-V loads and charging to a 14-V auxiliary battery. Given the space constraints within vehicles, LDCs require exceptionally high power density. Many topologies incorporating current doubler rectifiers are widely used for low voltage and high current applications, notably in LDCs. However, the current doubler rectifier necessitates four magnetics components, including a leakage inductor, a transformer, and two filter inductors, as shown in Fig. 1(a). This configuration leads to inefficiencies in cost, and a complex manufacturing process. In order to achieve high power density, employing integration technique proves to be effective method for reducing the volume of magnetic components [1-3]. Therefore, this paper proposes a new all-in-one magnetic structure to integrated all magnetic components into a single core, resulting in cost reduction, minimized volume and losses, and simplified manufacturing process, as shown in Fig. 1(b). Various combinations of primary side circuit and current doubler rectifier is widely used for LDCs, such as phase shift full bridge (PSFB), active clamp flyback forward (ACFF), push-pull,… To verify the performance of the proposed magnetic structure, a PSFB with current doubler is considered as representative example.

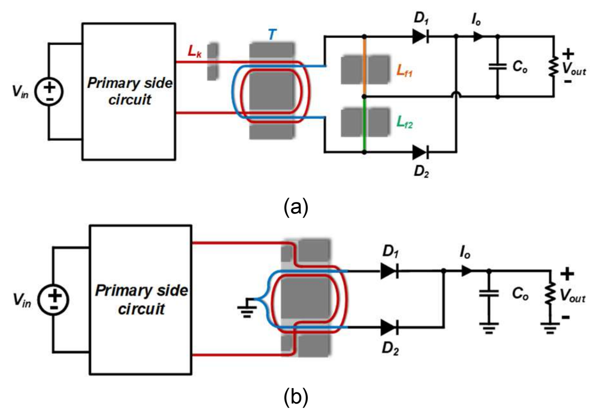


Fig.1 Power converter with current doubler converter: (a) with separated magnetic components, (b) with proposed all-in-one

2. Proposed all-in-one magnetic structure for LDC with current doubler rectifier

For LDC application, many topologies incorporating current doubler rectifier are widely used, classified into two types base on the applied voltage waveform (v_{ab}): symmetrical and asymmetrical. Fig. 2 shows the representative examples, with the PSFB converter in Fig. 2(a) representing the symmetrical type and the ACFF converter in Fig. 2(b) representing the asymmetrical type. However, current doubler rectifier circuits include four magnetic components: a leakage inductor, a transformer, and two filter inductors. This separated magnetic occupies large volume of the power converter.

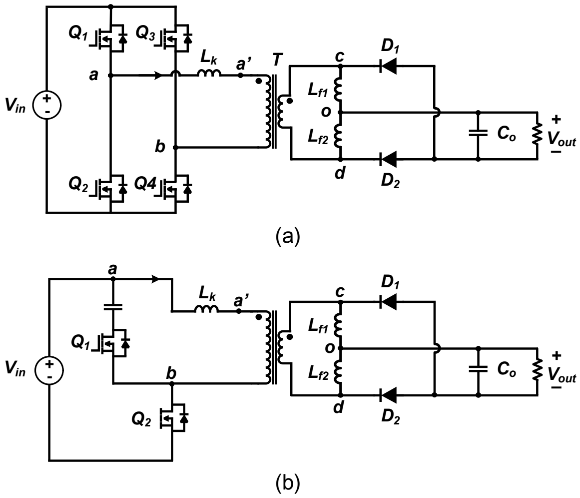


Fig. 2. Applicable topologies (a) PSFB converter with symmetrical applied voltage vab (b) ACFF converter with asymmetrical applied voltage vab

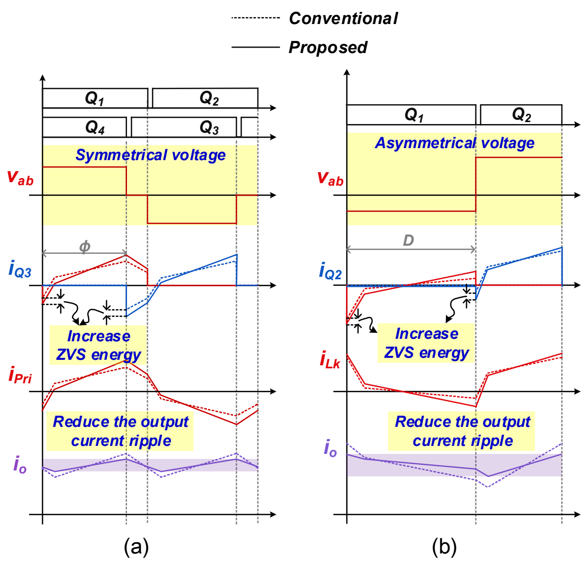


Fig.3. Key waveform comparisons of the conventional and proposed magnetics: (a) for symmetrical applied voltage type, (b) for asymmetrical applied voltage type.

To reduce the magnetic volume, a new all-in-one magnetic structure is proposed. By integration technique, the required number of core is minimized, reducing costs and simplifying the manufacturing process. Comparisons of key waveforms between the conventional separated and proposed all-in-one structure for both symmetrical and asymmetrical types are shown in Fig. 3. It is evident that the proposed magnetic in both types increases the ZVS turn-on energy and reduces output ripple current. This increase in ZVS energy allows for the use of smaller leakage inductance to achieve the entire ZVS under various load and voltage ranges. As a result, the proposed magnetic reduces the effect of duty loss.

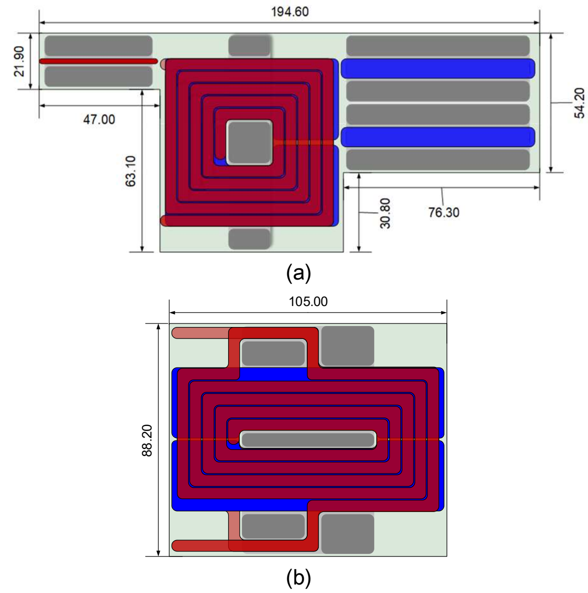


Fig. 4. Detailed dimentions of magnetic structure: (a) Separated leakage inductor Lk, transformer T, and filter inductors Lf1 and Lf2. (b) Proposed all-in-one magnetic.

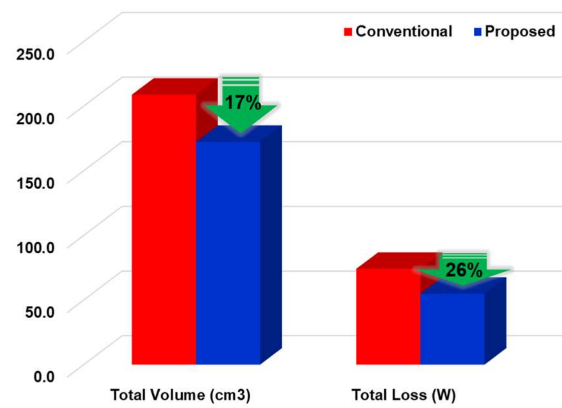


Fig.5. Comparison of the proposed all-in-one magnetic with the conventional separated magnetic.

In order to verify the performance of the proposed all-in-one magnetic structure, a design with both conventional separated and proposed magnetic structure for a PSFB converter is considered. The detailed dimensions of both structures are shown in Fig. 4. The results show that the proposed converter reduces 17% of total volume and 26% of total magnetic loss, as shown in Fig. 5.

3. Experimental results

In Fig. 6, a 3kW 800V 12V PSFB converter was built to verify the theoretical claims of the proposed all-in-one core structure. The prototype achieves 8.4kW/L of power density with the converter height of 18.5mm. The prototype utilizes the AIMCQ120R060M1T

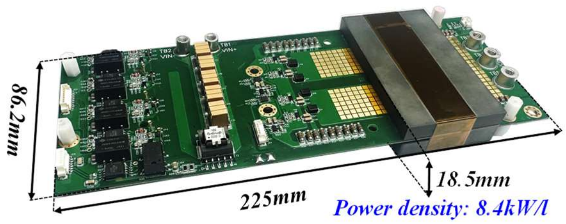


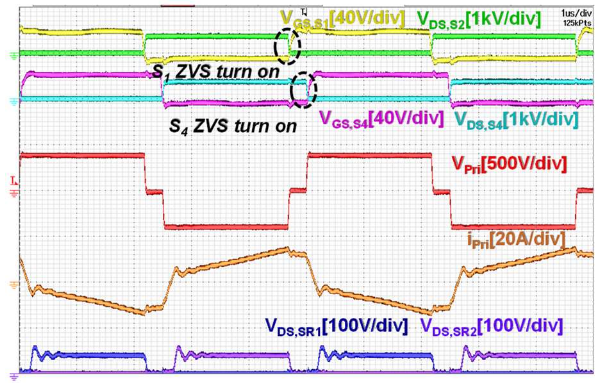
Fig.6. 3kW, 200kHz, 800V-12V PSFB converter prototype with the all-in-one core.

Fig.7. Measurement of peak efficiency.

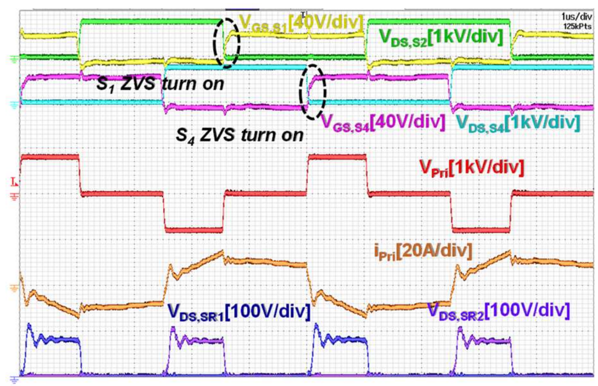
tch on the primary side and the IAUTN12S5N018T switch on the secondary side, both of which are the sample switches provided by Infineon. The converter can operate under wide voltage range: V_{in} = 340V - 800V and V_o = 11.6V - 15.3V. The converter can achieve 95.5% of peak efficiency at V_{in} = 340V, V_o = 15.3V, and P_o = 1.6kW as shown in Fig. 7. In Fig. 8, the experimental waveforms are shown that all switches can achieve ZVS under wide voltage range. It is evident that the proposed converter achieves entire ZVS turn-on under wide voltage range.

4. Conclusions

An all-in-one magnetic structure has been proposed to integrate all the magnetic components in the current doubler rectifier circuit. The proposed structure can apply to various topologies including current doubler rectifier. By the proposed integrated technique to the representing PSFB converter, results show that the proposed core structure can reduce the total volume by 17% and the total loss by 26%. In order to validate the effectiveness of the proposed core structure, a 3kW 800V 12V prototype of PSFB current doubler rectifier with the proposed all-in-one magnetic core structure has been built. The prototype converter achieved peak efficiency of 95.5% at V_{in} = 340V, V_o = 15.3V, and P_o = 1.6kW. The prototype with proposed all-in-one magnetic structure achieves 8.4kW/L.



(a)



(b)

Fig.8 Experiment results at 3kW, Vo = 14V conditions with (a) Vin = 340V, (b) Vin = 800V.

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.

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