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3kW Power Supply Design with Easy Manufacturability for 48 V Bus Power Architecture

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Abstract—The increase of power requirements per server rack, especially in the 48V bus architecture is demanding the increase of rated power and power density per power supply to fit as many power supplies in the server rack power shelf as possible. Due to the trade-off between fabrication cost and efficiency (running cost) of the power supply, the design of an efficient yet less labor-intensive power supply is important. This paper discusses methods to design the DC-DC unit of the 3kW power supply for the 48V architecture with easier manufacturability and lower cost. Prototype for 400V/48V 3kW 1MHz is demonstrated.

Keywords— Resonant converter, 48V architecture, planar magnetics.

INTRODUCTION

Datacenters have been switching focus from the 12 V to the 48V power architecture, as shown in Fig. 1, for several reasons [1]:

- The 48V power architecture has less dissipation loss on the bus as it uses higher voltage.
- A 48V battery bank is connected directly to the 48V bus to support the loads during energy shortage which saves the loss of the extra UPS in the 12 V architecture.

Recently, the demand for higher power per server rack is increasing [2], and a power supply unit with high power and high power density is needed. The power supply unit is required to deliver 3kW or higher with high power density and high efficiency. In addition, simple manufacturability and assembly are crucial to reducing the cost of the power supply. This paper

focuses on the design of the DC-DC converter based on the resonant converter. Resonant converters feature soft-switching which reduces the device switching loss and allows pushing switching frequency without sacrificing device loss. The paper introduces two designs; the first one is based on a full-bridge LLC resonant circuit, and the second design is based on a full-bridge CLL converter. The converter utilizes GaN devices to push the switching frequency to 1MHz, which allows to reduce the magnetic size and achieve a high power density. In addition, with the help of high frequency, the magnetic design can be switched from Litz wire magnetics [3] to planar magnetics using PCB. High power designs have significant transformer conduction loss. A matrix of transformers can help to reduce the conduction loss in the transformer winding and secondary side devices as well [4]. The two introduced designs are based on a 6-layer PCB that integrates all magnetic components and active switches of the converter and introduce low profile converter design.

400V/48V DC-DC CONVERTER DESIGN FOR 3kW POWER SUPPLY

Here, we introduce two design methods based on planar magnetics and easy manufacturability:

A. Full-bridge LLC design with planar magnetics

The first design is based on the well-known LLC converter. Full bridge LLC converter is used with 600V GaN devices on the primary side and 150V GaN on the secondary side. Fig. 2a shows the equivalent circuit of the first design. Four elemental transformers are used to form a matrix transformer. Each elemental transformer has a 2:1 turns ratio. The secondary winding of each elemental transformer is connected to the center-tapped rectifier and the output filter capacitors of the four transformers are connected in parallel. Even though matrix transformer is beneficial from a conduction loss point of view, the concept of matrix transformer increases the size of the transformer size as it uses multiple transformers. The increase of size from matrix transformer is counteracted by the increase of switching frequency to reduce the size and magnetic integration of the four transformers [5] [6] into one double UI core as shown in Fig. 2b. The secondary and primary windings are interleaved to reduce the AC winding loss. For the LLC, a significant amount of resonant inductance value is important to achieve voltage regulation through a wide gain range. The inductance here is implemented by the means of extending the primary

Fig.1. 12V power architecture and 48V architecture for datacenters

Fig.2. Fullbridge LLC converter with Matrix of four transformer. (a) circuit, (b) Implementation of transformer and inductor with 6 layer PCB (2 layers for shielding)

winding to wind an extra UI core. The matrix transformer core and inductor core can be separated or integrated into one 6 leg core. This design integrates all magnetic and active components into one PCB. The power density of the converter is $400\text{W}/\text{in}^3$, and the efficiency is over 97%. Fig. 3 shows implemented prototype of 1MHz 3kW DC-DC using the first design method where the whole converter including magnetic components is included in a single 6 layer PCB.

B. Full-bridge CLL design with planer magnetics

The first design with LLC implements a resonant inductor on the primary side of the transformer using UI core. The implementation of a resonant inductor comes with the expense

Fig.3. Generation 1: 1MHz 3kW LLC converter in 6-leg core, power density $400\text{ W}/\text{in}^3$

of an extra footprint. In the second design, the resonant inductor is implemented within the matrix transformer by utilizing the transformer leakage. A fifth leg is added between the four transformer legs to confine and enhance the leakage flux of the transformer and increase the leakage inductance. However, with the original winding arrangement of the matrix transformer (fig. 2b), the winding is identical on all four legs. This symmetry in winding results in symmetry in the flux in the four legs and the resulting flux going through the 5th center leg is zero. Therefore, the winding is rearranged as in Fig. 3b to create leakage flux in the center leg by breaking the symmetry in winding between the four transformers. In the example in Fig.3, the secondary winding is relocated without making any change on the primary winding. Blue secondary is active for the first half cycle and red secondary is active for the second half cycle. This will cause leakage flux to pass through the center leg. By relocating the secondary winding, the physical leakage inductance is found on the secondary side which can be verified by using the reluctance model and finite element simulation as well. This way, this example winding structure can be used in a three-element CLL resonant circuit as shown in Fig. 3a. Different combinations of winding arrangements will result in different leakage inductance values on both primary and secondary sides.

Fig.4 Fullbridge LLC converter with Matrix of four transformer. (a) circuit, (b) Implementation of transformer and inductor with 6 layer PCB (2 layers for shielding)

Fig.5. Generation 2 with 5-leg core, power density $550\text{W}/\text{in}^3$

Fig.6. Tested efficiency of LLC and CLL converters

The second design with a 5-Leg core structure provides the benefit of higher power density and smaller footprint while still using 6 layer PCB for easier manufacturability. The projected power density of this converter is 550W/in³.

As a conclusion, this paper has presented high frequency design and magnetic integration methods to provide solutions to high-efficiency high power density converters with yet easy implementation and assembly.

REFERENCES

- [1] J. H. D. F. Donghwi Kim, "48V Power Delivery to Grantley Reference Board," in *APEC*, 2016.
- [2] P. Fernandez, "Open Rack V2.1 Standard compliant 48V System Design - High Efficiency power and Lithium BBU units," in *OCP summit*, 2018.
- [3] Delta, "DPR 3000 EnerGE Single phase rectifier," Delta.
- [4] E. Herbert, "High frequency matrix transformer". United States Patent US5093646A, 1989.
- [5] D. Huang, S. Ji, F. C. Lee, "LLC resonant converter with matrix transformer," *IEEE Trans. Power Electron.*, vol. 29, no. 8, pp. 4339-4347, Aug. 2014.
- [6] C. Fei, F. C. Lee and Q. Li, "High-Efficiency High-Power-Density LLC Converter With an Integrated Planar Matrix Transformer for High-Output Current Applications," *IEEE Transactions on Industrial Electronics*, vol. 64, no. 11, pp. 9072-9082, Nov. 2017.
- [7] F. C. Lee, Q. Li, and A. Nabih, "High Frequency Resonant Converters: An Overview on the Magnetic Design and Control Methods," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 1, pp. 11-23, Feb. 2021, DOI: 10.1109/JESTPE.2020.3011166...
- [8] Mohamed Ahmed, Ahmed Nabih, Fred C. Lee, Qiang Li, "High-efficiency, High-density Isolated/ Regulated 48V Bus Converter with a Novel Planar Magnetic Structure," in *to be published*, 2019.
- [9] Ahmed Nabih, Mohamed H Ahmed, Qiang Li, Fred C Lee, "Transient Control and Soft Start-Up for 1-MHz LLC Converter With Wide Input Voltage Range Using Simplified Optimal Trajectory Control," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 1, pp. 24-37, 2020.