A 48-V Input LLC Converter for Data Center Applications using Hybrid Control Structure

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Introduction:

The adoption of 48V for the power distribution of data center applications is accelerating in response to higher efficiency requirements. Taking into account the growing demands of intensive computing application, cloud computing, higher power requirements for CPUs and GPUs, the benefits of adopting 48V DC bus racks become more significant. The 48V power racks contribute to lower conduction losses and less dissipated heat in the data center facility. Compared to the conventional 12V power distribution, it provides better power conversion efficiency at rack level, and works at lower current levels to deliver a 16X reduction in power distribution losses.

Compared to conventional dual stage $48\,V-1{,}3\,\&\,5\,V$ power systems (with intermediate $12\,V$ DC bus), the direct $48\,V$ POL converter improves the system efficiency and power density with simpler implementation and lower cost. The large conversion ratio between the input and output voltage levels dictate the need of using isolating type DC/DC converters. Additionally, the high current stress in data center applications require the design of an efficient and a compact DC/DC configuration. Higher efficiency can be achieved by applying soft switching techniques along with the proper choice of the used configuration. While a compact design can be achieved through the application of high frequency switching on the used DC/DC converter. In this submission, a single stage LLC converter is proposed with a hybrid control structure where both frequency and phase shift modulation are used.

Proposed Solution:

In this Poster, an LLC converter is proposed as a single stage point of load (POL) converter with a hybrid frequency/phase shift control structure.

The use of resonant converters had been a popular topic of research in the field of power electronics for the past two decades. One of the most promising resonant converters to be employed in data center DC/DC conversion applications is LLC converter as shown in Fig. 1. The main benefit of LLC converter over the aforementioned ones is the narrow switching frequency range with light load and the zero voltage switching capability at zero to light load conditions. Thus, LLC converter is an excellent candidate for front-end DC/DC converter applications especially at high frequency and high current ratings.

It is clear from Fig. 2 that any variation in the switching frequency would highly impact the converter voltage gain. Additionally, the loading conditions affect the voltage gain specifically at low frequency values. Thus, the most employed control technique conventionally for an LLC converter is frequency modulation where a closed loop control is applied to continuously track the output voltage at different loading conditions and input voltage values. This is specifically important for data center applications as the input voltage for the 48 v POL converters varies in the range of 40 v-60 v

Additionally, a soft switching technique is applied on the DC/DC converter in order to increase the system efficiency by reducing the switching losses through operating either in the zero-voltage switching (ZVS) or the zero-current switching (ZCS) region.

However, the main drawback of the aforementioned control technique is the need to vary the switching frequency in a large range at light load conditions. This leads to increasing the electromagnetic interference, audible noise in the system and lowering the overall system efficiency at high switching frequency values (due to the increased switching losses). Thus, in this poster, frequency control is coupled with phase shift control to narrow the frequency operating range while maintaining the soft switching features of the designed resonant LLC converter. The current and the voltage waveforms of Mosfets QA-QD using the proposed control are shown in Figs. 3-8 in different operating regions.

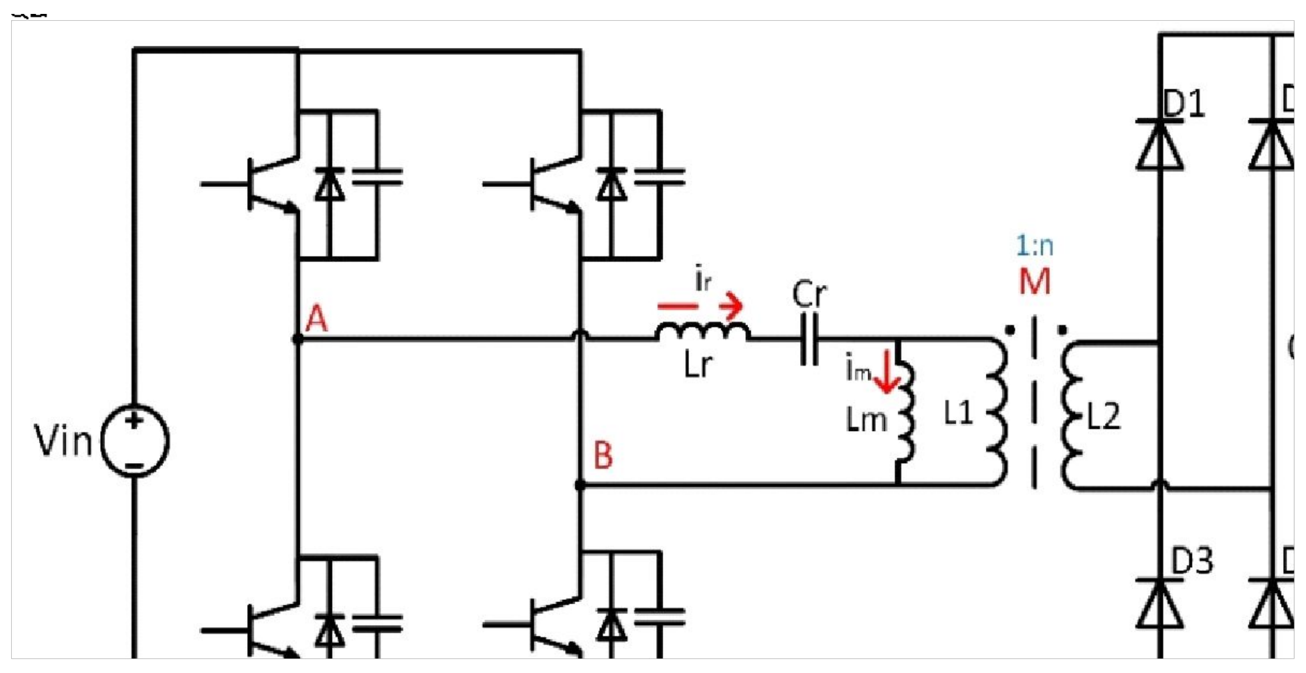

Figure 1. Full Bridge LLC Resonant Converter.

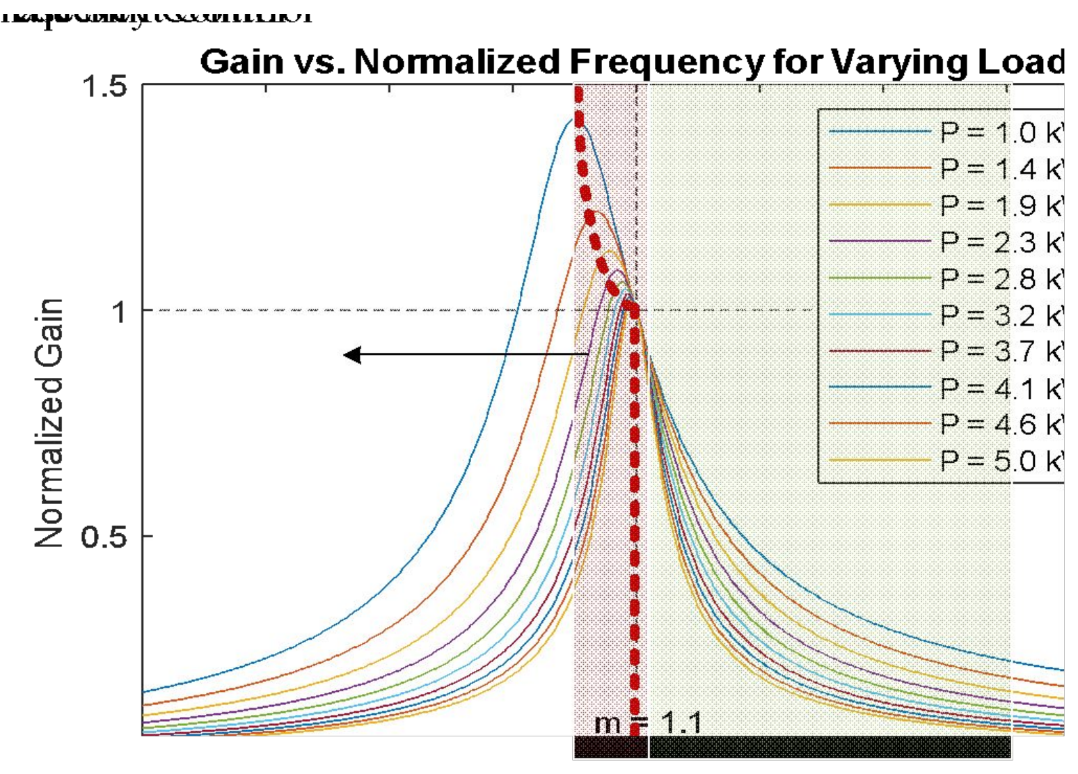

Figure 2. Gain Bode Plot of an LLC Converter.

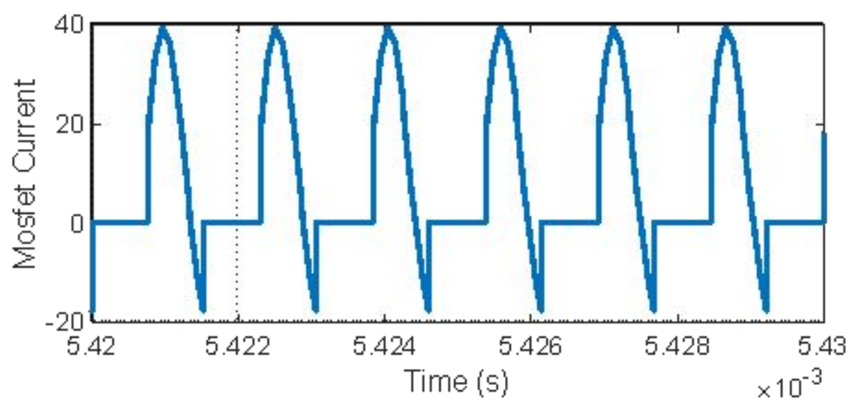

Figure 3. Mosfet Current during ZCS

Figure 4. Mosfet Current During Full resonance

Figure 5. Mosfet Current During ZVS

Figure 6. Mosfet Voltage during ZCS

Figure 7. Mosfet Voltage during full resonance

Figure 8. Mosfet Voltage during ZVS

Thus, a novel control structure is applied on the LLC converter where frequency modulation is combined with phase shift control to achieve ZVS at all loading conditions with near ZCS operation. The need for a low voltage output leads to high current rates. Thus, lower conduction losses is highly desirable in these systems. Consequently, GAN semiconductor devices are investigated for these DC-DC modules to demonstrate a single stage DC-DC converter prototype capable of driving high power CPUs, GPUs and ASICs with 48V nominal input voltage, 5V or below output voltage.

As shown in Fig. 2, the frequency control is limited to a narrow range, thereafter, phase shift control is applied. As the proposed converter operates with a narrow switching frequency variation, a small transformer core can be selected leading to a decreased core size and higher system efficiency. Thus, the proposed converter can be designed optimally for a selected operating switching frequency resulting in a maximized system efficiency. Both the frequency control and the phase shift control logical implementation are shown in Figs. 9-10.

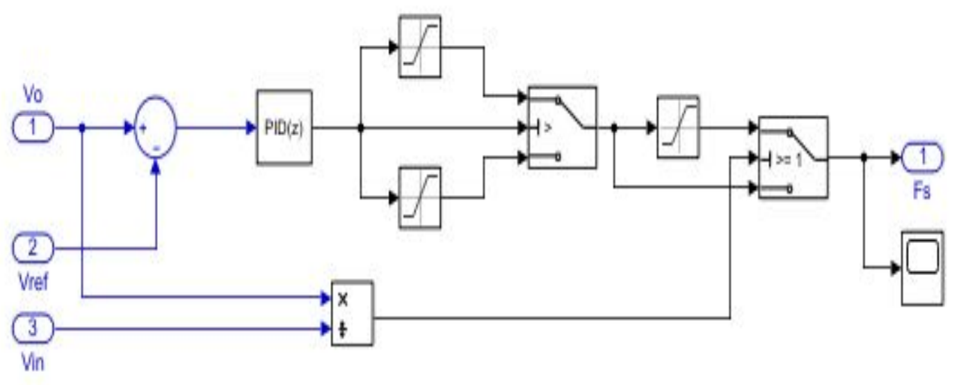

Figure 9. Frequency Control Implementation.

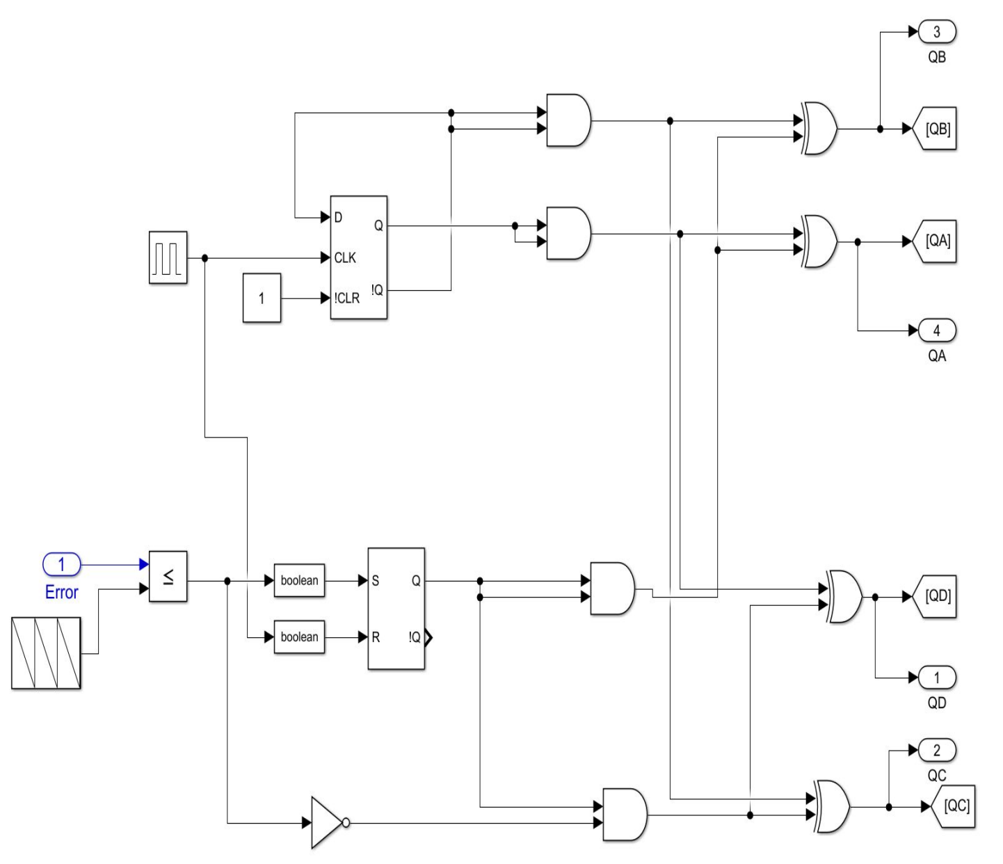

Figure 10. Phase Shift Control Implementation.

An LLC converter with 5 kW capacity is currently under development at CPEC in SJSU to verify the system experimentally.

1. D. Huang, S. Ji, and F. C. Lee, “LLC Resonant Converter With Matrix Transformer,” IEEE Transactions on Power Electronics, vol. 29, no. 8, pp. 4339–4347, Aug. 2014.
2. M. Mu and F. C. Lee, “Design and Optimization of a 380–12 V High Frequency, High-Current LLC Converter With GaN Devices and Planar Matrix Transformers,” IEEE Journal of Emerging and Selected Topics in Power Electronics, vol. 4, no. 3, pp. 854–862, Sep. 2016.
3. 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