2023 IEEE Transportation Electrification Conference and Expo, Asia-Pacific (ITEC Asia-Pacific) | 979-8-3503-1427-4/23/$31.00 ©2023 IEEE | DOI: 10.1109/ITECAsia-Pacific59272.2023.10372279

A New Light Load Efficiency Improving Scheme Utilizing SiC-MOSFET Features of Dynamic Gate Drive Threshold Voltage with Smart Driving Design for Phase Shift Full Bridge Converter

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***Abstract*—A phase shift full bridge (PSFB) power converter is mainstream topology for server power supplies. It is suitable for high power and efficiency application, however, it could not reach zero voltage switching (ZVS) during the light load operation region. In this articles, dynamic gate drive threshold voltage with smart driving design to achieve light load efficiency improving are introduced and adopted into SiC-MOSFET-based PSFB for full load range operation and severe environment. The advantages and disadvantages of this light load efficiency improving scheme is shown to demonstrate its feasibility and comparing to the pre-loading control scheme for loss breakdown analysis.**

Keywords—phase shift full bridge, zero voltage switching, dynamic gate drive, SiC-MOSFET.

I. Introduction

Server power supplies are widely applied in server devices such as Big Data, IoT and AI technologies. SiC, one of the third generation semiconductor materials, is featured with remarkable performance to realize the new application and meet the advanced requirement. Most of these DC to DC topologies in server power supplies are phase shifted full bridge converters for achieving high efficiency designs. However, there is a disadvantage that the phase shifted full bridge converters could not operate at zero voltage switching during light load[1]-[6]. It would cause extremely high power loss and thermal problem for power supply application. A lot of improving technologies are proposed. The modification technologies of the leakage inductance to extent the load operation range[7][10]. The extended phase shift control is to reach the high transferred efficiency under light load control[11]. This paper would disclose the voltage control with dynamic gate driver. The next section discloses the principle of the proposed driving operation. Section 3 would show the dynamic gate drive threshold voltage with smart driving design and experimental result. Section 4 is the conclusion.

II. Princeple of Propose Driving Operation

The conventional PSFB converters achieve zero-voltage switching condition while the resonant inductor energy is larger than the resonant capacitor energy. It is shown as

$$E_{L_r} > E_{C_r} \tag{1}$$

where E_{L_r} is the resonant inductor energy and E_{C_r} is the resonant capacitor energy. C_r is the corresponding parasitic capacitance of the PSFB circuit. In fact, the corresponding parasitic capacitance would involves the transformer distributed capacitance (C_{Tr}), the corresponding parasitic capacitance C_r is given as

$$C_r = 2\,C_{oss} + C_{Tr} \tag{2}$$

The total energy stored in the corresponding parasitic capacitance is shown as below

$$E_{C_r} = 0.5\,C_r\,{V_i}^2 = 0.5\,(2\,C_{oss} + C_{Tr})\,{V_i}^2 \tag{3}$$

where V_i is the converter input voltage and the resonant capacitor energy is shown as

$$E_{L_r} = 0.5\,L_r\,{I_p}^2 \tag{4}$$

where I_p is the resonant current flows through the inductor. Therefore, from (1), (3) and (4), the relationship of the zero-voltage switching condition can be easily obtained

$$L_r > \frac{(2\,C_{oss}+C_{Tr})\,\,{V_i}^2}{{I_p}^2} \tag{4}$$

From the above relationship, assume that the equivalent parasitic capacitance and input voltage are constant, then the resonant inductance should be big enough to reach ZVS when no load or light load. On the contrary, the resonant inductance could be small to achieve ZVS when heavy load. Based on the above relationship, the conventional phase-shifted full-bridge converters are generally designed to meet the requirements of medium and heavy load operation to achieve ZVS.

III. Dynamic Gate Drive Threshold Voltage With Smart Driving

A easy way to avoid hard switching under light load is using the pre-loading control technique to add a output dummy load that can bypass the light load operation region. A dynamic gate drive threshold voltage with smart driving design is used to adaptively adjust the on-resistance of SiC-MOSFET to change the impedance and power load of the converter, so that the PSFB converter can achieve the purpose of zero-voltage switching under light load. Fig. 1 is illustrative leveraged SiC-MOSFET module for PSFB. The applied SiC-MOSFET module for demonstrating the applicability is composed by PDX040C120Z as element chip which is developed by POTENS Semiconductor Corp.[12], and the basic rating specification of SiC-MOSFET are listed as table I. Fig. 2 is the pre-loading control method of the PSFB converter. In this method, the logic control circuit is used to perform timing control and adjust the dummy load to eliminate the hard switching state of the power switch,. It changes the output load of the circuit at light load, so that the circuit will not be in a hard switching state. In other words, their concept uses the different load area to reach ZVS of the PSFB converter. Fig. 3 depicts the dynamic gate drive threshold voltage with smart driving controller of the PSFB converter. Fig. 4 depicts the control block of the dynamic gate drive threshold voltage with smart driving. The output of PWM control includes two parts: duty cycle and amplitude of voltage. The duty cycle is determined by output voltage and the amplitude of PWM voltage is determined by the current of the resonant inductor and relation of gate resistance w.r.t. gate threshold voltage to increase the current of the resonant inductor. Finally, the loss breakdown would be compared to the pre-loading control technique of the PSFB converter. The estimated power loss comparison under light load operation region is shown in Fig. 5.

IV. Conclusion

The proposed PSFB DC to DC converter is constructed by dynamic gate drive threshold voltage with smart driving design utilizing SiC-MOSFET features is proposed to improve the efficiency of the PSFB converter during the light load. It mainly discusses the dynamic gate voltage control for changing the loss of the power switch to effectively avoid the operation range where ZVS cannot be reached. The results are shown that power loss of the conventional PSFB converter is worse than the proposed PSFB converter during the light load condition. The proposed PSFB converter could improve the light load efficiency and reduce the operating temperature of power devices during light load operation region. Therefore, the efficiency from light load to heavy load could be optimized by utilizing the proposed PSFB converter.

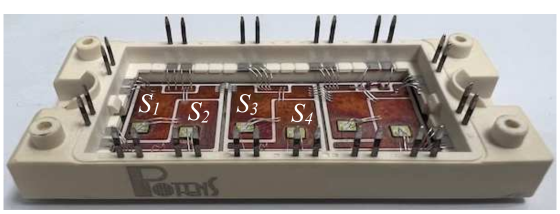

Fig. 1. Illustrative leveraged SiC-MOSFET module of PSFB converter

TABLE I. The Basic Rating Specification

Symbol	*Parameter*	*Rating*
V_{DS}	Drain-source voltage	1200V
I_D	Drain current-continuous (T_C=25°C)	60A
I_{DM}	Drain current-pulse	150A

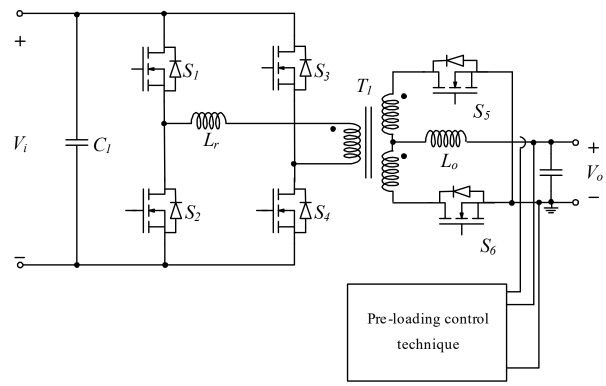

Fig. 2. Pre-loading control technique of the PSFB converter.

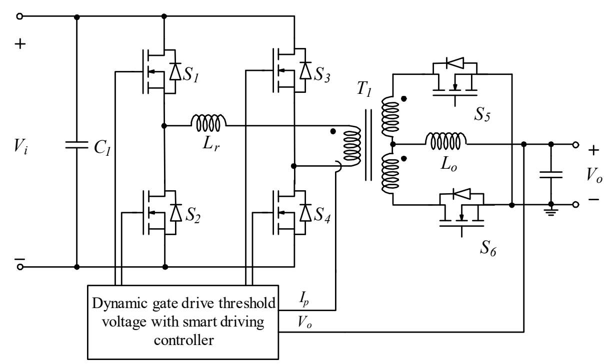

Fig. 3. The dynamic gate drive threshold voltage with smart driving for the proposed PSFB converter.

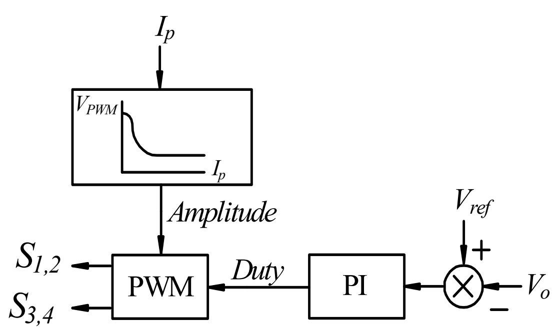

Fig. 4. Control block of the dynamic gate drive threshold voltage with smart driving

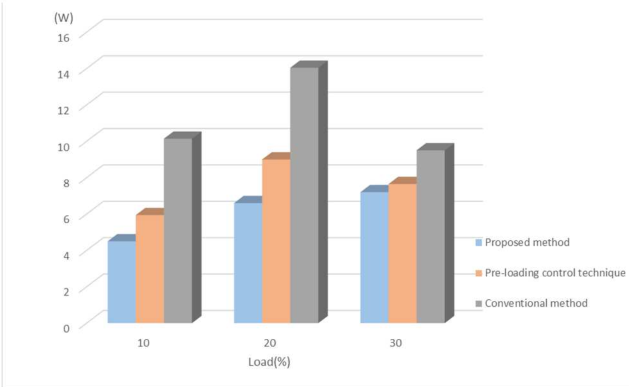

Fig. 5. Estimated power loss comparison of conventional and proposed method

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