A Zero Voltage Transition based Boost Converter for Power Factor Correction and its Application

Mr. Vinaya B.K[1] Mr. Rajath Shankar.P.S[2]
[1,2]Assistant Professor
[1,2]Department of Electrical & Electronics Engineering
[1,2]SIT, Mangalore

Abstract— This project proposes a novel soft-switched auxiliary resonant circuit to provide a zero-voltage transition at turn on for a conventional pulse width modulated boost converter in a power factor correction application. The proposed auxiliary circuit enables a main switch of the boost converter to turn on under a zero-voltage switching condition and simultaneously achieves both soft-switched turn on and turn off. The proposed circuit is designed to satisfy several design constraints, including space saving, low cost and easy fabrication. As a result circuit is easily realized by a low-rated MOSFET and a small inductor.

Key words: ZVT, PFC, Zero Voltage Transition based Boost Converter

I. INTRODUCTION

Power converters are developing very quickly for various applications such as power factor correction (PFC) and switched-mode power supply. One major force driving this development is the emergence of powerful and cost-effective integrated power multichip modules, based on the new concepts of building structure and advanced packing technology. This leads to several performance improvements in power converters, such as high efficiency, high power density, and long-term reliability, with decreasing converter cost.

Moreover, various converter techniques and topologies have been proposed and used in order to improve converter performance. One widely used technique is soft switching, which generates electrical resonance between a capacitor and an inductor during a short turn-on/off period and consequently achieves zero-voltage and/or zero-current switching. Several benefits of this technique include improving efficiency, reducing stress, and removing electromagnetic interference (EMI) noises, but its major drawback is the requirement for an auxiliary circuit to create resonance phenomena at switching time. The requirement of the auxiliary circuit increases component costs and circuit complexity of the converter system, yet even for applications in industry and home appliances, where cost and easy fabrication are the most important aspects of the design, there are still impediments to using soft-switching techniques.

In recent years, the integrated multichip power module, which itself incorporates the aforementioned soft-switching transition technique, has been in demand because of the high performance requirements for energy efficiency, harmonics, EMI, and so on, due to enhanced regulations from government and energy societies. In addition, other market competitors are consistently reducing their costs. However, these performance requirements are significantly challenged in the sense of space constraints, thermal management, high costs, and unwieldy fabrication. That is, the auxiliary circuit to realize the soft switching technique in conventional zero-voltage transition(ZVT) circuitry requires at least three components of large size(i.e., inductor, MOSFET, and diode), which consumes too much space and increases costs.

This project proposes a novel auxiliary resonant circuit that can be easily incorporated into a multichip power module. The proposed circuit is simple, being realized with a low rated MOSFET and a small inductor due to full utilization of the conduction resistance RDS (on) of MOSFET while providing ZVT turn-on switching for a conventional pulse width modulated (PWM) converter. At the same time, the MOSFET of the auxiliary circuit operates under soft-switching conditions during both turn-on and turn-off transitions. In addition, by minimizing the number of components and the required power rating, the circuit can easily and cost-effectively be incorporated into multichip power modules. The operating principle and theoretical analysis of the proposed circuit are explained in detail. We also provide design considerations and experimental verification for the target of the proposed PWM boost converter for home application with PFC.

When a new control strategy of a converter or a drive system is formulated, it is often convenient to study the system performance by simulation before building the breadboard or prototype. The simulation not only validates the systems operation, but also permits optimization of the systems performance by iteration of its parameters. Besides the control and circuit parameters, the plant parameter variation effect can be studied. Valuable time is thus saved in the development and design of the product, and the failure of components of poorly designed systems can be avoided. The simulation program also helps to generate real time controller software codes for downloading to a microprocessor or digital signal processor. To solve the objective of this paper MATLAB/ SIMULINK software is used.

II. PRINCIPLE OF OPERATION

This project proposes a novel auxiliary resonant circuit that can be easily incorporated into a multichip power module. In addition, by minimizing the number of components and the required power rating, the circuit can easily and cost-effectively be incorporated into multichip power modules.

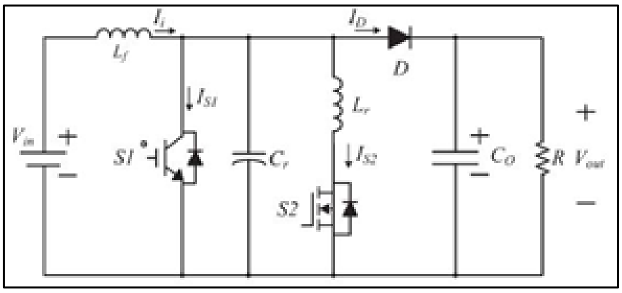

Fig. 1: Proposed ZVT-PWM Boost Converter topology

Fig. 1 shows the circuit scheme of the proposed ZVT-PWM boost converter. This converter differs from the conventional PWM boost converter of a resonant branch, which consists of a resonant inductor L_r, a resonant capacitor C_r, and an auxiliary switch S_2 (MOSFET). Generally, auxiliary switch S_2 has a lower power rating than that of main switch S_1 [insulated-gate bipolar transistor (IGBT)]. Resonant capacitor C_r is the sum of the parasitic capacitor of S_1 and others incorporating multichip module technology. The proposed circuit is simple, being realized with a low rated MOSFET and a small inductor due to full utilization of the conduction resistance R_{DS} (on) of MOSFET while providing ZVT turn-on switching for a conventional pulse width modulated (PWM) converter. At the same time, the MOSFET of the auxiliary circuit operates under soft-switching conditions during both turn-on and turn-off transitions. In addition, by minimizing the number of components and the required power rating, the circuit can easily and cost-effectively be incorporated into multichip power modules.

The following assumptions are made in order to easily describe the steady-state analysis during one switching cycle:

1) Input voltage V_{in} is constant.
2) Output capacitor C_0 is sufficiently large.
3) Main inductor L_f is sufficiently large.
4) Main inductor L_f is much larger than auxiliary inductor L_r ($L_f > L_r$).

For one switching cycle, the proposed circuit operations can be divided into eight stages.

- Stage 1: Main switch S_1 and auxiliary switch S_2 are off before t_0. When the auxiliary softly turns on at t_0, the auxiliary inductor L_r current linearly increases from 0 to I_i at t_1. During this period, diode D is conducted.
- Stage 2: In this stage, the circuit starts to resonate between Lr and Cr. Auxiliary inductor current I_{Lr} continues to increase up to I_{S2_peak}. C_r is discharged until the resonance brings its voltage to zero.
- Stage 3: When the anti-parallel diode is conducting, the main switch current flows negatively for a very short time. Main switch voltage V_{CE_S1} is zero at t_3. Main switch S_1 is turned on under the zero-voltage switching condition.
- Stage 4: Main switch current I_{S1} increases, whereas auxiliary switch current I_{S2} decreases. Therefore, the sum of both switch currents is equal to I_i. In this stage, IGBT and MOSFET can be changed to the voltage source V_{sat_S1} and on-resistance $R_{DS\ (on)\ \_S2}$, respectively, for analysis. This is because the characteristic of the current flowing through the two switches is determined by the resistance elements of each switch.
- Stage 5: Auxiliary switch S_2 is softly turned off. The flowing current in the auxiliary inductor is converted to voltage on the parasitic capacitor of S_2. Auxiliary inductor current I_{Lr} is zero at t_5.
- Stage 6: This stage is identical to the conventional PWM boost converter behaviour. D is turned off at t_5. Main switch S_1 conducts and I_i flows while the auxiliary circuit is inactive.
- Stage 7: At this stage, the main switch is turned off, and resonant capacitor C_r is linearly charged up to V_{in} voltage. Diode D is turned on naturally at t_7.
- Stage 8: This stage is a freewheeling condition as in the conventional PWM boost converter. Main switch S_2 turns on again at t_0 and the operation mode repeats.

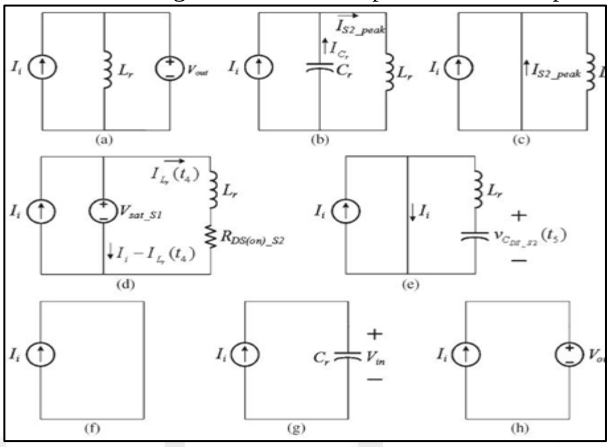

Fig. 2: Equivalent circuits during one switching cycle

The theoretical waveforms are shown in the fig. 3.

III. DESIGN PROCEDURE

A. Specification of the proposed ZVT-PWM Boost Converter

The design specification of an air conditioner with a PFC converter is shown in Table 1. A prototype of the proposed ZVT-PWM boost converter as shown in fig. 4. It has been built to verify the analytical result using the components in Table 2.

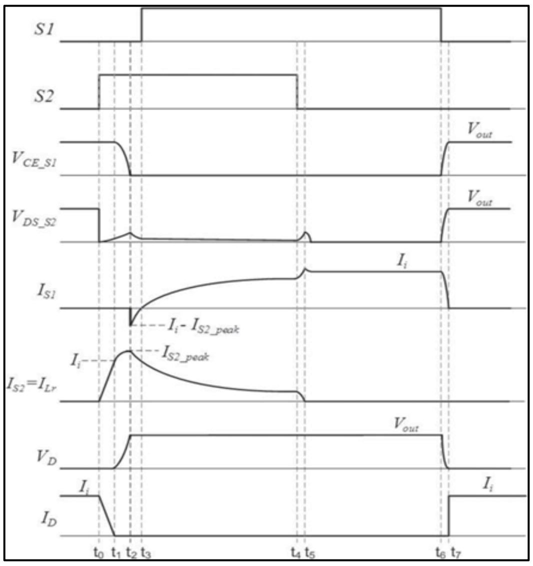

Fig. 3: Theoretical waveforms of the proposed ZVT-PWM boost converter

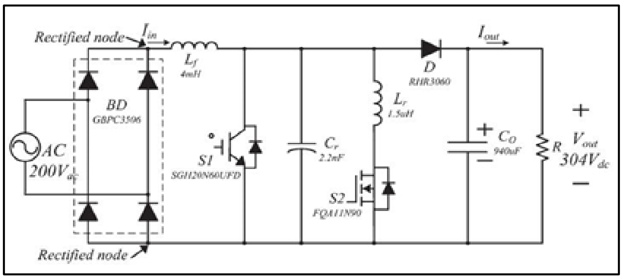

Fig. 4: Proposed ZVT-PWM boost converter.

Parameters	Description	Values
V_{in}	Input voltage	200Vac
V_{out}	Output voltage	304Vdc
V_{out_ripple}	Output voltage variation	Vout±5%
I_{L_ripple}	Boost inductor current variation	Ii±5%
f_{line}	Input voltage frequency	50Hz or 60Hz
f_{sw}	Switching frequency	16kHz
P_{out}	System capacity	1.8kW
η	Boost converter efficiency	$\eta > 0.95$

Table 1: Specifications of the proposed ZVT-PWM Boost Converter

Parameters	Description	Values
L_f	Boost inductance	4mH
L_r	Auxiliary inductance	1.5uH
S1	Main switch(FGH40N60SFD)	IGBT, 20A, 600V $V_{CE(sat)}$=2.3V
S2	Auxiliary switch(FQA11N90)	MOSFET, 11A, 900V $R_{DS(on)\_S2}$=0.96 Ω
$R_{G\_off\_S2}$	Gate off-resistance of the S2	130Ω
C_O	Output capacitance	940uF(470uF*2ea)
C_r	Auxiliary capacitance	2.2nF
BD	Bridge diode(GBPC3506)	35A, 600V
D	Main diode(RHR3060)	30A, 600V

Table 2: Components value of the proposed ZVT-PWM Boost Converter

B. Selection of L_f and C_0

To minimize both the current ripple and the voltage ripple, we design *Lf* and *CO* to be as large as possible. However, the system cost increases according to the stringency of the specification. The optimized *CO* and *Lf* of the proposed ZVTPWM boost converter are designed by following equations

$$Lf > \frac{(V_{\text{in(min)}})^2}{2 \cdot I_{i\_\text{ripple}}\% \cdot f_{\text{sw}} \cdot P_{\text{out}} \cdot \eta}\left(1 - \frac{\sqrt{2} \cdot V_{\text{in(min)}}}{V_{\text{out}}}\right)$$

$$Co > \frac{P_{\text{out}}}{2\pi \cdot f_{\text{line}} \cdot V_{\text{out\_ripple}} \cdot V_{\text{out}}}.$$

C. Selection of S2

The turn-on condition, auxiliary switch current *IS*2 flows through the drain to the source for a very short time (a few microseconds) and its duty ratio is less than 0.1. In this paper, the on-time of *S*2 is within 3 μs. This design value of the auxiliary switch *S*2 can be applied in order to select the MOSFET device by using the pulse drain current specifications. Usually, the maximum pulse drain current is about four times the value of the continuous drain current. In addition, the predicted value of IS2_peak can be applied to select the auxiliary switch. The auxiliary switch MOSFET should be more than twice the calculated value of IS2_peak while the pulse drain current is 45.6 A. In order to achieve a rapid decrease in the slope of IS2, S2 is selected to satisfy the following condition:

Vsat_S1 < IS_S2 R DS(on)_S2

Where IS_S2 is the maximum continuous drain source forward current of S2. When the R DS(on) of S2 is selected sufficiently large, the voltage stress of S2 is much smaller than its rated voltage.

IV. SIMULATION OUTPUT WAVEFORMS

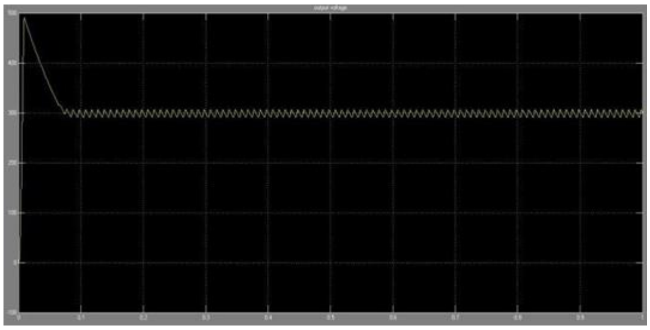

Fig. 5: Output voltage for the proposed ZVT-PWM boost converter

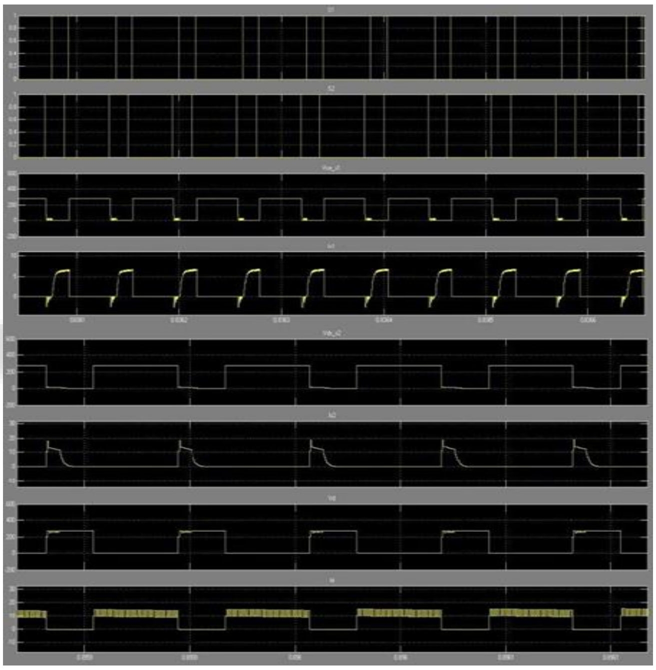

Fig. 6: Simulation waveforms for the proposed ZVT-PWM boost converter

V. CONCLUSION

This paper has presented a new ZVT-PWM boost converter with an active snubber. The output voltage of PWM boost converter i.e. 304V can be integrated in to the multichip power module. The proposed method has a reduced circuit complexity, a minimized auxiliary Lr and reduced CE. The proposed circuit has the main and auxiliary switches are confirmed to have ZVT turned on and softly turned on and off. Hence the voltage stress of the auxiliary switch is quite low.

ACKNOWLEDGMENT

I would like to express my gratitude towards my parents & to my Co-author for their kind co-operation and encouragement which help me in completion of this paper.

REFERENCES

[1] T.-S. Kwon and S.-I. Yong, "The new smart power module for up to 1 Kw motor drives application," J. Power Electron., vol. 9, no. 3, pp. 456–463, May 2009.
[2] T. S. Kwon, J. H. Song, and S. I. Yong, "New generation of smart power modules for up to 3 kW motor drive applications," presented at the PCIM, Shanghai, China, 2008.
[3] T.-S. Kwon, J.-M.Lee, K.-S.Park, Y.-C.Kim, and H.-H. Kim, "Development of new smart power module for home appliances motor drive applications," in Proc. IEEE IEMDC, 2011, pp. 95–100.
[4] G. Hua, C. Leu, and F. C. Y. Lee, "Novel zero-voltage-transition PWM converters," IEEE Trans. Power Electron. vol. 9, no. 2, pp. 213–219,Mar. 1994.
[5] R. L. Lin and F. C. Lee, "Novel zero-current-switching-zero-voltage switching converters," in Proc. IEEE PESC, 1996, pp. 438–442.
[6] G. Hua and F. C. Lee, "A new class of zero-voltage-switched PWM converter," in Proc. HFPC, 1991, pp. 245–251.
[7] R. L. Lin, Y. Zhao, and F. C. Lee, "Improved soft-switching ZVT converters using coupled inductor based active snubber cell," in Proc. VPEC, Sep. 1997, pp. 195–201.
[8] M. L. Martins, J. L. Russi, and H. L. Hey, "Zero-voltage transition PWM converters: A classification methodology," Proc. Inst. Elect. Eng.—Electr.Power Appl., vol. 152, no.2, pp. 323– 334, Mar. 2005.
[9] H. Bodur and A. F. Bakan, "A new ZVT-PWM DC–DC converter," IEEE Trans. Power Electron., vol. 17, no. l, pp. 40–47, Jan. 2002

