

# ZVZCT PWM Boost DC-DC Converter

İsmail Aksoy, Hacı Bodur, Nihan Altıntaş

**Abstract**—This paper introduces a boost converter with a new active snubber cell. In this circuit, all of the semiconductor components in the converter softly turns on and turns off with the help of the active snubber cell. Compared to the other converters, the proposed converter has advantages of size, number of components and cost. The main feature of proposed converter is that the extra voltage stresses do not occur on the main switches and main diodes. Also, the current stress on the main switch is acceptable level. Moreover, the proposed converter can operate under light load conditions and wide input line voltage. In this study, the operating principle of the proposed converter is presented and its operation is verified with the Proteus simulation software for a 1 kW and 100 kHz model.

**Keywords**—Active snubber cell, boost converter, zero current switching, zero voltage switching.

## I. INTRODUCTION

**P**ULSE WIDTH MODULATION (PWM) DC-DC converters are commonly preferred in as renewable energy sources, electrical vehicles, power factor correction, fuel cell etc. applications because of their perfect dynamic performance, high power density, fast transition response and simple control. To obtain high power density, the switching frequency must be increased. But the high switching frequency leads to high switching losses and electromagnetic interference (EMI). So, it decreases the performance and efficiency of the converter. The (SS) techniques are proposed and improved for resolving all of these adverse effects [1]-[13].

In basic zero voltage transition (ZVT) converter [1], main switch turns on with ZVT perfectly with the help of a snubber cell with parallel resonance. Multiple ZVT converters are suggested to solve the problems in basic ZVT converter [1], [4]-[7], [11]-[14], [17], [18].

In the basic zero current transition (ZCT) converter [2], the main switch turns off under zero current switching (ZCS) and zero voltage switching (ZVS) with the help of a snubber cell with a serial resonance. Multiple ZCT converters are suggested to solve the problems in basic ZVT converter [2], [3], [13], [19], [20].

In order to solve these problems in ZVT and ZCT converters ZVT-ZCT-PWM DC-DC converters are suggested. This circuits which are formed by combining the ZVT and ZCT methods, are suggested in [9], [15], [16].

In this study, a boost converter with a new active snubber

cell, which turns on the main switch by ZVT and turns off it by ZCT, was introduced. The ZVZCT PWM boost dc-dc converter, where the developed snubber cell is used, not only has the properties of previously presented ZVT and ZCT converters but it also serves to solving their problems. Compared to the other converters, the proposed converter has advantages of size, number of components and cost. In the proposed converter, the cost and size of the snubber inductances are relatively low. As the switching losses in the proposed converter are too low, L and C size can be reduced by increasing the operating frequency. But the timing of the control signals must be precise at high frequencies and, the use of faster control platforms can be required for the signal generation. The steady state analysis of the proposed converter is presented. Also the simulation results of the proposed converter operated under 1 kW and 100 kHz is given in detail.

## II. OPERATING PRINCIPLES OF CONVERTER

The circuit scheme of the proposed converter can be seen in Fig. 1. In this circuit,  $V_i$  is input voltage source,  $V_o$  is output voltage,  $L_F$  is main inductor,  $C_F$  is output filter capacitor,  $S_1$  is main switch and  $D_F$  is main diode. The main switch consists of a main transistor  $T_1$  and its body diode  $D_1$ . In the active snubber cell,  $L_{sa}$  and  $L_{sb}$  are snubber inductors,  $C_s$  is snubber capacitor,  $S_2$  is auxiliary switch and  $D_3$ ,  $D_4$  are auxiliary diodes.  $T_2$  and  $D_2$  are the transistor and its body diode of the auxiliary switch, respectively. The capacitor  $C_p$  is assumed to be the sum of the parasitic capacitor.

In the steady state analysis of the converter, semiconductor devices, inductors and capacitors are assumed ideal. Also, it is assumed that input and output voltages and input current are constant.

The theoretical waveforms of the proposed converter are given in the Fig. 2. Operating principles of the proposed converter is analyzed under two headings. The first one is the turn-on process of the main switch and the other one is the turn-off process of the main switch respectively.

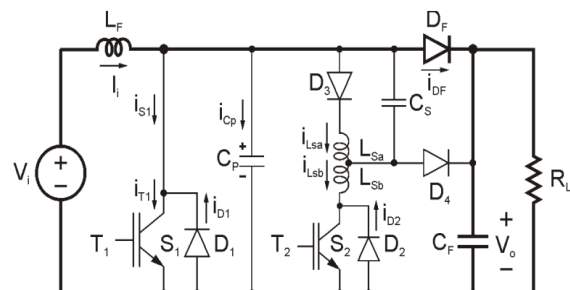


Fig. 1 Circuit scheme of the proposed converter

I. Aksoy is with the Department of Electrical Engineering, Yildiz Technical University, Istanbul, Turkey (phone: +90-212-3835816; fax: +90-212-3835858; e-mail: iaksoy@yildiz.edu.tr).

H. Bodur and N. Altintas are with the Department of Electrical Engineering, Yildiz Technical University, Istanbul, Turkey (e-mail: bodur@yildiz.edu.tr, naltin@yildiz.edu.tr).

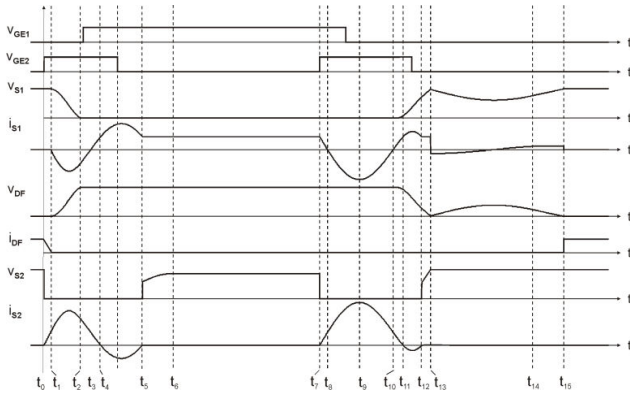


Fig. 2 Theoretical waveforms of the proposed converter

#### A. Turn-on Process ( $t_0$ - $t_7$ )

Turn-on process of the main switch starts by applying the control signal of  $T_2$  while  $D_F$  is on state and conducts the input current. A resonance starts between snubber inductances  $L_{sa}$ ,  $L_{sb}$  and snubber capacitor  $C_s$ .  $T_2$  current ( $i_{S2}$ ) rises and  $D_F$  current ( $i_{DF}$ ) falls simultaneously as a result of the resonance.  $i_{S2}$  reaches  $I_i$  and  $i_{DF}$  falls to zero.  $T_2$  and  $D_3$  are turned on with ZCS due to the series connected inductances. The main diode  $D_F$  is turned off with nearly ZCS.

A resonance between parasitic capacitor  $C_p$ , snubber inductances  $L_{sa}$  and  $L_{sb}$  and snubber capacitor  $C_s$  starts. The energy stored in the parasitic capacitor  $C_p$  is transferred to the resonant circuit and  $v_{Cp}$  becomes 0. The diode  $D_1$  is turned on. The resonant which is between snubber inductances  $L_{sa}$ ,  $L_{sb}$  and snubber capacitor is still continued. The diode  $D_1$  is conducts the excess current of snubber inductance  $L_{sb}$  from the  $I_i$ . When the snubber inductance  $L_{sb}$  current drops to input current,  $D_1$  is turned off under ZCS. Control signal is applied to  $T_1$  while the  $D_1$  is on, thus the main switch is turned on with ZVT and  $i_{S1}$  is starting to rise. When the  $i_{S1}$  reaches  $I_i$ ,  $i_{S2}$  current becomes zero and then  $D_2$  is turned on. The control signal of  $T_2$  is removed when the  $D_2$  on state, so that auxiliary switch  $T_2$  is perfectly turned off under ZCT.

A resonance between snubber inductance  $L_{sa}$  and snubber capacitor  $C_s$  starts and the energy from  $L_{sa}$  is transferred to snubber capacitor  $C_s$ . Turn on process of the main switch is completed. The main transistor  $T_1$  conducts the  $I_i$  and the snubber circuit is not active.

#### B. Turn-off Process ( $t_7$ - $t_{15}$ )

Turn-off process of the main switch starts by applying the control signal of  $T_2$  while  $T_1$  is on state and conducts the input current. A resonance starts between snubber inductance  $L_{sb}$  and snubber capacitor  $C_s$ .  $i_{S2}$  rises and  $i_{S1}$  falls simultaneously as a result of the resonance.  $i_{S2}$  reaches  $I_i$ ,  $i_{S1}$  falls to zero and  $D_1$  is turned on with ZCS at the same instant.  $T_2$  is turned on with ZCS due to the series connected inductances.  $T_1$  is now turned off; the switching will occur with zero voltage and zero current.

A resonance between snubber inductor  $L_{sb}$ , snubber inductor  $L_{sa}$  and snubber capacitor  $C_s$  starts. When the resonance current falls to  $I_i$ ,  $D_1$  is turned off under ZCS. A

new resonance starts between  $C_p$ ,  $L_{sa}$ ,  $L_{sb}$  and  $C_s$  under the input current.  $i_{S2}$  continues to decrease due to the resonance and falls to 0. As a result of this  $D_2$  is turned on. The control signal of  $T_2$  is removed when the  $D_2$  on state, so that auxiliary switch  $T_2$  is perfectly turned off under ZCT. After that  $D_2$  becomes off state and  $C_p$  is charged by input current linearly in the one circuit.

A new resonance begins between the snubber inductance  $L_{sa}$  and snubber capacitor  $C_s$ .  $D_4$  is turned on when the sum of  $v_{Cp}$  and  $v_{Cs}$  becomes equal to  $V_o$ . a resonance between  $L_{sa}$ ,  $C_s$  and  $C_p$  starts under the input current. When the  $L_{sa}$  current becomes zero, the energy stored in the inductor is completely transferred to the capacitors and to the load.  $C_p$  is charged and  $C_s$  is discharged linearly under the input current.  $C_p$  voltage reaches  $V_o$  and  $C_s$  voltage falls to 0 simultaneously.  $D_F$  is turned on with ZVS. Turn off process of the main switch is completed.  $D_F$  continues conducting the input current  $I_i$  and the snubber circuit is not active.

### III. DESIGN PROCEDURE

The design of the new active snubber cell proposed for boost converters is not complicated. To improve the efficiency, the active snubber cell should be designed to achieve soft switching for the main switch for complete load and line conditions. Design criteria of the new active snubber cell are explained below, depending on the soft switching of the main switch, main diode and auxiliary switch.

The capacitor  $C_p$  represents total parasitic capacitor of the power semiconductor devices.

The value of  $L_{sa}$  must be at least 2 times of  $L_{sb}$  value in order to turn off the auxiliary switch  $S_2$  with ZCT. This condition can be defined as,

$$L_{sa} \geq 2L_{sb} \quad (1)$$

$L_{sb}$  is selected to allow a current rise rate to be the maximum input current at most, within the auxiliary switch turn-on process and its current rise time.

$$\frac{V_o}{L_{sb}} t_r \leq I_{i\max} \quad (2)$$

$t_r$  is the rise time of the auxiliary switch current.

$C_s$  value depends on the value of  $C_p$ ,  $L_{sa}$  and  $L_{sb}$ . The maximum value of the resonance current should be greater than the input current, ZVT and ZCT operation should be provided. In case of choosing these component values to be high, the sum of transient intervals and thus conduction losses increase.

### IV. SIMULATION RESULTS

It is realized a prototype of proposed converter with a new active snubber cell by 1 kW and 100 kHz in Proteus simulation program. The simulation model of the proposed converter is given in Fig. 3. In this model, boost converter is operated in CCM at  $V_i = 200V$  and  $V_o = 400V$ .  $C_p$  is selected

as 1 nF,  $C_s$  is selected as 4.7 nF,  $L_{sa}$  is selected as 4  $\mu$ H and  $L_{sb}$  is selected as 2  $\mu$ H.

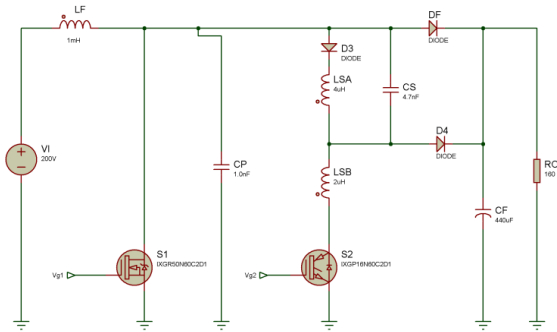


Fig. 3 Simulation model of the proposed converter

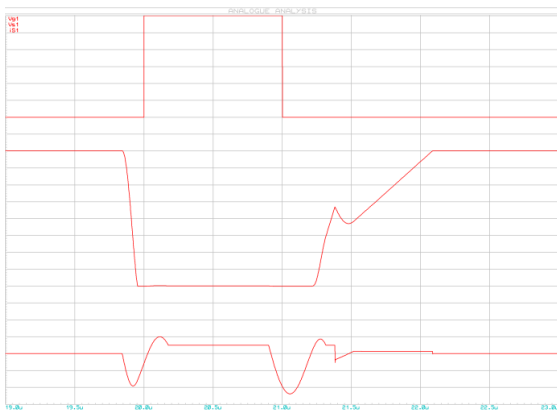


Fig. 4 Control signal, voltage and current waveforms of  $S_1$

Fig. 4 shows the control signal, voltage and current waveforms of the main switch. As shown in Fig. 4,  $S_1$  is operated under soft switching at both turn-on and turn-off process. The control signal of the main switch is applied or removed when the body diode is in the on state. So that, the main switch turn-on process is realized under ZVT and turn-off process is realized under ZCT perfectly. There is no additional voltage stress on switch and acceptable current stress occurs for a short time interval.

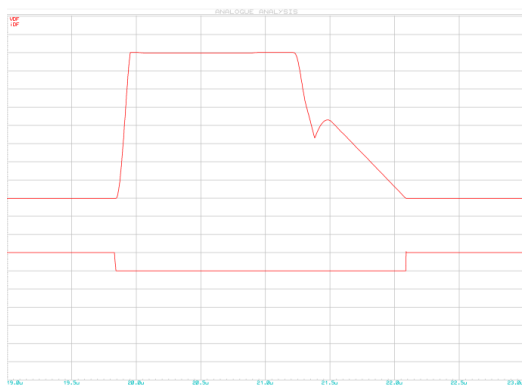


Fig. 5 Voltage and current waveforms of  $D_f$

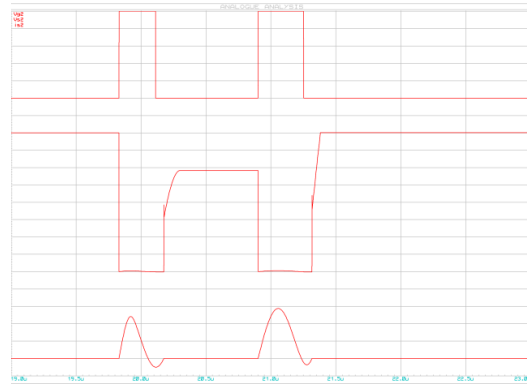


Fig. 6 Control signal, voltage and current waveforms of  $S_2$

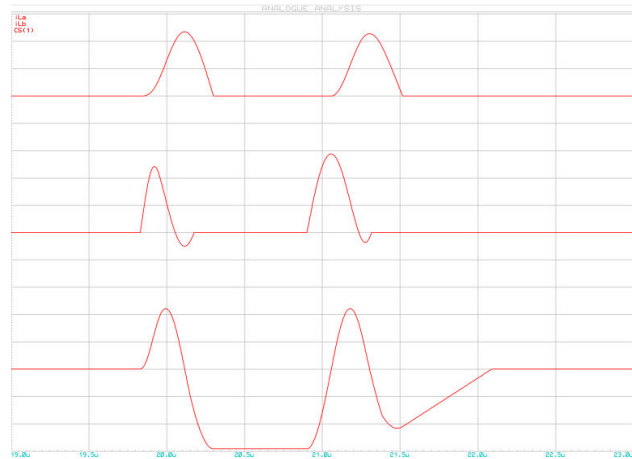


Fig. 7  $L_{sa}$  and  $L_{sb}$  currents and  $C_s$  voltage waveforms

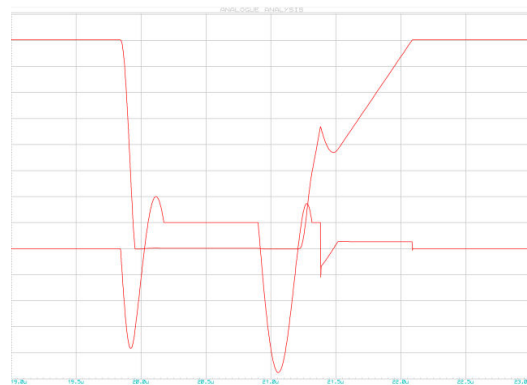


Fig. 8 Voltage and current waveforms of  $S_1$  under light load

As shown in Fig. 5, the main diode turns on and off with soft switching, ZCS and ZVS respectively. Also, the main diode has no additional voltage and current stresses.

Fig. 6 shows the control signal, voltage and current waveforms of the auxiliary switch. As shown in Fig. 6,  $S_2$  is operated under soft switching at both turn-on and turn-off process. The control signal of the main switch is removed when the body diode is in the on state. So that, the main switch turn-off process is realized under ZCT

perfectly. The turn-on process is realized under ZCS. The rise speed of the current is limited because of the  $L_{sb}$  snubber inductance connected in series with the auxiliary switch. As shown from the waveforms, the auxiliary switch is not subjected to any additional voltage stresses while it operates under soft switching scheme.

The waveforms of the resonant inductance currents and capacitor voltage are shown in Fig. 7. In the turn-on process of the main switch, the voltage across the snubber capacitor starts to increase when the resonance is started with the auxiliary transistor's turn-on. At the end of the turn-on process, the capacitor voltage is equal to approximately half of the output voltage and then it becomes zero at the end of the turn-off process. It can be seen that from the figure, the energy which stored in inductances or capacitors is transferred with the help of resonance.

Fig. 8 shows voltage and current waveforms of the main switch under light load conditions. In this case, load resistance is selected as 1.6 k $\Omega$  and so the output power is 10% of the nominal output power. It can be seen that from this figure,  $S_1$  is still operated under soft switching at both turn-on and turn-off process.

#### V.CONCLUSION

In this study, a boost converter with a new active snubber cell, which turns on the main switch by ZVT and turns off it by ZCT, is introduced. When the proposed converter is compared to the other converters, the proposed converter has advantages of size, number of components and cost. The proposed converter not only has the properties of previously presented ZVT and ZCT converters but it also serves to solving their problems.

In the proposed converter, the main switch turn-on and turn-off with ZVT and ZCT respectively. The main diode turns on with ZVS and turns off with ZCS. The auxiliary switch turns on with ZCs and turns off with ZCT. Also the other diodes operate under soft switching. All the semiconductor devices are not subjected any voltage stresses. In the proposed converter, soft switching conditions are maintained under light load conditions and wide input line voltage.

The proposed ZVZCT PWM boost dc-dc converter is simulated in Proteus simulation software for a 1 kW and 100 kHz model. The results which are taken from the simulation circuit seem to be in full compliance with the theoretical analysis.

#### REFERENCES

- [1] G. Hua, C. S. Leu, Y. Jiang, and F. C. Lee, "Novel Zero-Voltage-Transition PWM Converters," IEEE Transactions on Power Electronics, vol. 9, pp. 213-219, Mar. 1994.
- [2] G. Hua, E. X. Yang, Y. Jiang, and F. C. Lee, "Novel Zero-Current-Transition PWM Converters," IEEE Transactions on Power Electronics, vol. 9, pp. 601-606, Nov. 1994.
- [3] H. Mao, F. C. Lee, X. Zhou, H. Dai, M. Cosan, and D. Boroyevich, "Improved Zero-Current-Transition Converters for High-Power Applications," IEEE Trans. on Ind. Applicat., vol. 33, pp. 1220-1232, Sept./Oct. 1997.
- [4] J. G. Cho, J. W. Baek, G. H. Rim and I. Kang, "Novel Zero-Voltage-Transition PWM Multiphase Converters," IEEE Transactions on Power Electronics, vol. 13, pp. 152-159, Jan. 1998.
- [5] C. J. Tseng and C. L. Chen, "Novel ZVT-PWM Converters with Active Snubbers," IEEE Transactions on Power Electronics, vol. 13, pp. 861-869, Sept. 1998.
- [6] V. Grigore and J. Kyra, "A New Zero-Voltage-Transition PWM Buck Converter," in Proc. 9th Mediterranean Electrotechnical Conf. (MELECON98), Tel Aviv, Israel, vol. 2, 1998, pp. 1241-1245.
- [7] J. M. P. Menegaz, M. A. Co., D. S. L. Simonetti, and L. F. Vieira, "Improving the operation of ZVT DC-DC Converters," in Proc. 30th Power Electron. Spec. Conf. (PESC99), Charleston, vol.1, 1999, pp. 293-297.
- [8] K.M., Smith, and K.M., Smedley, "Properties and Synthesis of Passive Lossless Soft-Switching PWM Converters", IEEE Transactions on Power Electronics, vol.14, pp. 890-899, Sept. 1999.
- [9] C. M. de O. Stein, and H. L. Hey, "A True ZCZVT Commutation Cell for PWM Converters," IEEE Transactions on Power Electronics, vol. 15, pp. 185-193, Jan. 2000.
- [10] D. Y. Lee, B. K. Lee, S. B. Yoo, and D.S. Hyun, "An Improved Full-Bridge Zero-Voltage-Transition PWM DC/DC Converter with Zero-Voltage / Zero-Current Switching of the Auxiliary Switches," IEEE Trans. on Ind. Applicat., vol. 36, pp. 558-566, Mar. / Apr. 2000.
- [11] T. W. Kim, H. S. Kim, and H. W. Ahn, "An Improved ZVT PWM Boost Converter," in Proc. 31st Power Electron. Spec. Conf. (PESC00), Galway, Ireland, vol. 2, 2000, pp. 615-619.
- [12] H. Bodur and A. F. Bakan, "A New ZVT-PWM DC-DC Converter," IEEE Transactions on Power Electronics, vol. 17, pp. 40-47, Jan. 2002.
- [13] H. Yu, B. M. Song, and J. S. Lai, "Design of a Novel ZVT Soft-Switching Chopper," IEEE Transactions on Power Electronics, vol. 17, pp. 101-108, Jan. 2002.
- [14] D.Y., Lee, M.K., Lee, D.S., Hyun, and I. Choy, "New Zero-Current-Transition PWM DC/DC Converters Without Current Stress", IEEE Transactions on Power Electronics, vol.18, pp. 95-104, Jan. 2003.
- [15] H., Bodur, and A.F., Bakan, "A New ZVT-ZCT-PWM DC-DC Converter," IEEE Transactions on Power Electronics, vol. 19, pp. 676-684, May. 2004.
- [16] A.F., Bakan, H., Bodur, and I., Aksoy, "A Novel ZVT-ZCT PWM DC-DC Converter", 11th European Conference on Power Electronics and Applications (EPE2005), Dresden, 1-8, Sept. 2005.
- [17] C.M., Wang, "Novel Zero-Voltage-Transition PWM DC-DC Converters", IEEE Transactions on Industrial Electronics, vol.53, pp. 254-262, Feb. 2006.
- [18] W., Huang, and G., Moschopoulos, "A New Family of Zero-Voltage-Transition PWM Converters with Dual Active Auxiliary Circuits", IEEE Transactions on Power Electronics, vol. 21, pp. 370-379, Mar. 2006.
- [19] P., Das, and G., Moschopoulos, "A Comparative Study of Zero-Current-Transition PWM Converters", IEEE Transactions on Industrial Electronics, vol.54, pp. 1319-1328, June 2007.
- [20] M.R.; Amini, H.; Farzanehfard, "Novel Family of PWM Soft-Single-Switched DC-DC Converters With Coupled Inductors", IEEE Transactions on Industrial Electronics, vol.56, pp. 2108-2114, June 2009.

**I. Aksoy** was born in Cologne, Germany, in 1977. He received the B.S., M.S., and Ph.D. degrees in electrical engineering from Yildiz Technical University, Yildiz, Turkey, in 1999, 2001, and 2007, respectively. He was a Research Assistant from 1999 to 2008 and Asst. Prof. from 2008 to 2014 in the Department of Electrical Engineering, Yildiz Technical University. Since 2014 he has been working as a Assoc. Professor in the Department of Electrical Engineering at Yildiz Technical University. He has published over 20 journal and conference papers in the area of power electronics. He was also employed in three research projects concerning power electronics. His research subjects are power factor correction, switching power supplies, high frequency power conversion, and active and passive snubber cells in power electronics.