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 operates 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

PULSE 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

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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.
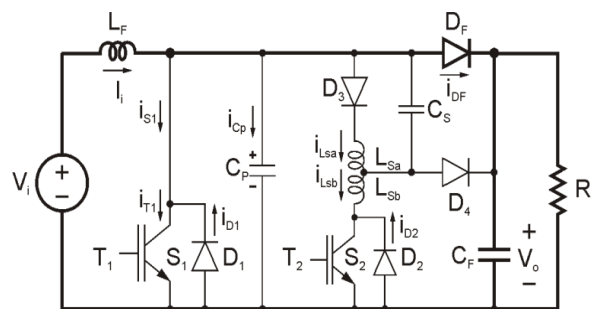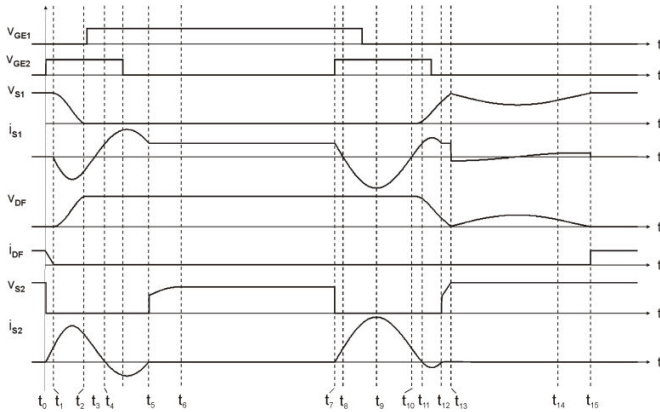

Fig. 1 Circuit scheme of the proposed converter

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Fig. 2 Theoretical waveforms of the proposed converter

A. Turn-on Process (t₀-t₇)

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 (t₇-t₁₅)

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 D2 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}, Cs 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,

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

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.

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

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 = 400 V. C_p is selected

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as 1 nF, C_s is selected as 4.7 nF, L_{sa} is selected as 4 uH and L_{sb} is selected as 2 uH.
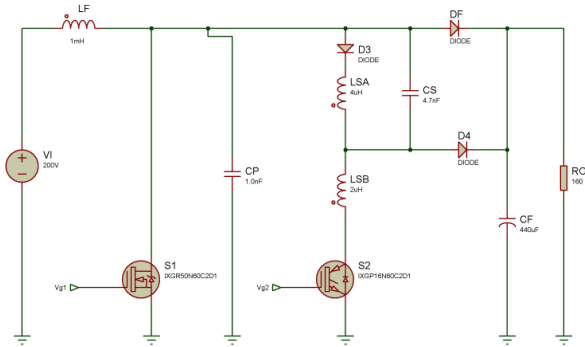

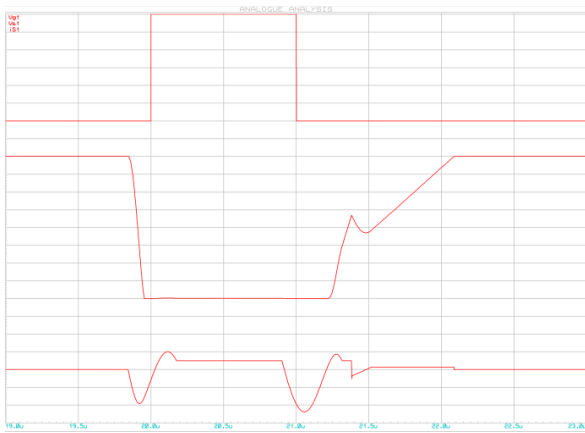Fig. 3 Simulation model of the proposed converter

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.
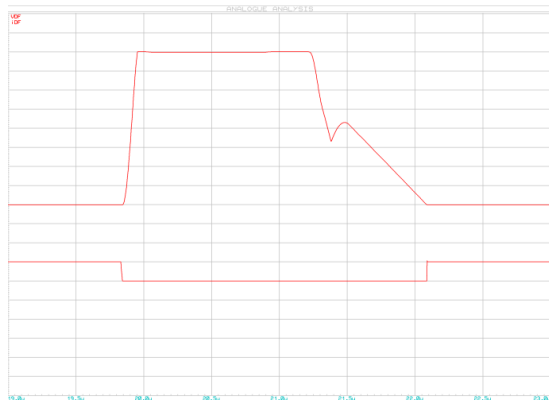

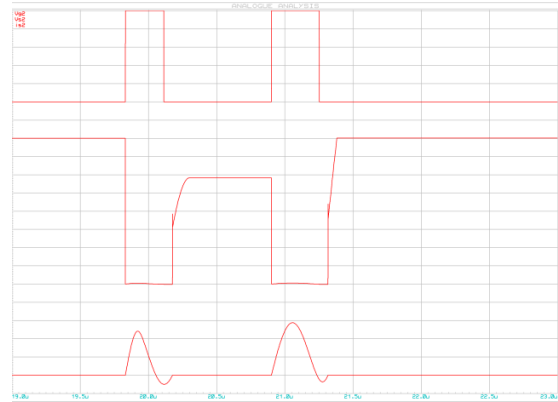Fig. 5 Voltage and current waveforms of D_F

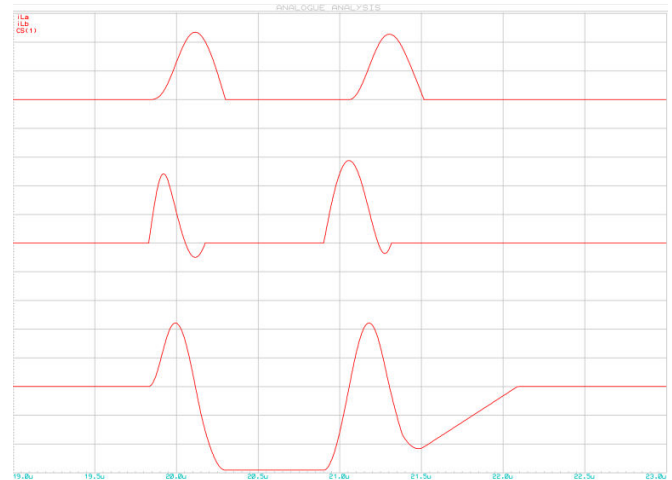Fig. 6 Control signal, voltage and current waveforms of S_2

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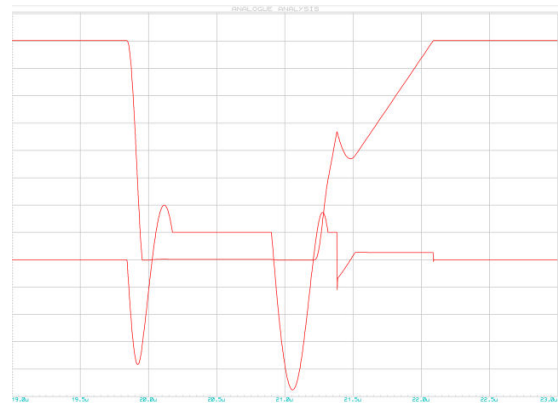

Fig. 8 Voltage and current waveforms of S_1 under light load

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 the body diode is in the on state. So that, the main switch turn-off process is realized under ZCT

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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 kΩ and so the output power is 10% of the nominal output power. It can be seen that form 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 witch 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.

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