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1 kW Power Factor Correction Soft Switching Boost Converter with an Active Snubber Cell

Yakup Sahin, Naim Suleyman Ting, Ismail Aksoy

Abstract**—**A 1 kW power factor correction boost converter with an active snubber cell is presented in this paper. In the converter, the main switch turns on under zero voltage transition (ZVT) and turns off under zero current transition (ZCT) without any additional voltage or current stress. The auxiliary switch turns on and off under zero current switching (ZCS). Besides, the main diode turns on under ZVS and turns off under ZCS. The output current and voltage are controlled by the PFC converter in wide line and load range. The simulation results of converter are obtained for 1 kW and 100 kHz. One of the most important feature of the given converter is that it has direct power transfer as well as excellent soft switching techniques. Also, the converter has 0.99 power factor with the sinusoidal input current shape.

Keywords**—**Power factor correction, direct power transfer, zero-voltage transition, zero-current transition, soft switching.

I. INTRODUCTION

IN the recent years, power factor correction (PFC) is a demanded feature for AC-DC power supplies. PFC circuits are used between bridge rectifier and output load for eliminating high harmonic content of the line current. The harmonic currents cause some problems as higher total harmonic distortion, poor power factor at input line voltage and current. The classical PFC circuits are usually composed of two stages. So, the cost is higher, and the control is more complex in two-stage PFC circuits [1], [2]. To overcome these problems, the single-stage PFC converters have been proposed in literature [3]-[5].

The single-stage PFC circuits have a common switch for regulation and PFC. So, their cost is lower, and the control is simpler. To obtain lower harmonic current, faster dynamic response and higher power density, PFC circuits should be operated at high frequency. However, their switching losses increase in high frequency since they are usually operated under hard switching (HS) [6], [7]. To reduce the switching losses, soft switching (SS) techniques have been proposed in literature [8]-[15].

The converter in [8] operates under SS conditionals for switches. The switches of the converters in [9]-[11] operate under SS without extra current or voltage stresses on the switches. In [12], the main switch turns off with HS. In [13], the SS is not provided under 0.5 duty cycle, and there is an additional current stress on the main switch. In [14], there is an additional current stress on the main switch. In [15], all of the switches operate under SS, but there are extra current stresses on the main and the auxiliary switches.

The ZVZCT PFC boost converter is shown in Fig. 1. In this converter, the main switch turns on under ZVT and turns off under ZCT. The main diode turns on under ZVS and turns off under ZCS. Also, there is no additional current or voltage stress on the main devices. The auxiliary switch and the auxiliary diodes both turn on and turn off under ZCS. The corresponding converter decreases EMI noises and operates even under a wide range of line and load voltages. Due to these features, this converter has a high power factor and lower total harmonic distortion.

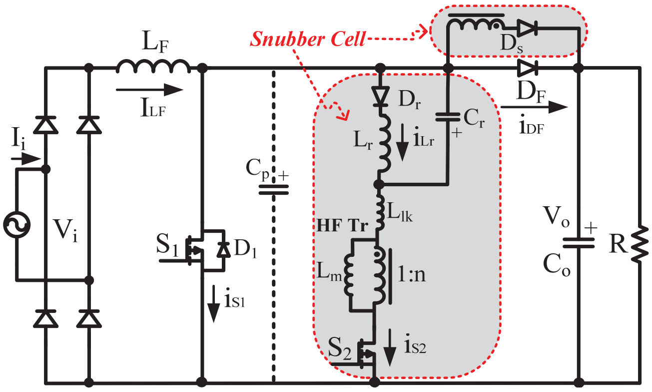

Fig. 1 The basic circuit scheme of the converter

II. STEADY STATE ANALYSIS OF THE CONVERTER

The circuit scheme of the 1 kW PFC ZVZCT boost converter with an active snubber cell is given in Fig. 1. For this converter, V_i is AC input voltage, V_o is DC output voltage, L_F is the main inductance, C_o is the output capacitor, R is the output load, S_1 is the main switch, S_2 is the auxiliary switch, and D_F is the main diode. D_1 is the internal diode of the main switch. C_p is the sum of the parasitic capacitors of the main switch and the main diode. L_r is the snubber inductance, L_{lk} is the leakage inductance, and L_m is the magnetization inductance of transformer, C_r is the snubber capacitor, D_r and D_s are the auxiliary diodes. Besides, I_i is the input AC current, I_{LF} is the main inductance current, i_{S1} is the current of main switch, i_{S2} is the current of auxiliary switch, i_{Lr} is L_r inductance current, and i_{DF} is the main diode current.

The following assumptions are taken into consideration while making theoretical analysis of the converter.

- Output voltage V_o and input current I_i are constant for one switching cycle.
- All semiconductor devices and resonant circuits are ideal.

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- The reverse recovery times of all diodes are not taken into account.

A. Turning on under ZVT for the Main Switch

Before turning on interval of the main switch, S_1 and S_2 switches are at off state. Then, a gate signal is applied to the auxiliary switch and it turns on under ZCS because of series inductance L_{lk}. Also, the main diode turns off under ZCS. After the auxiliary switch current reaches to I_{LF}, a resonance begins between the parasitic capacitor C_p and the snubber cell. So, the voltage of parasitic capacitor C_p falls to zero, and the internal diode of the main switch turns on under ZVS. Then, a gate signal of the main switch is applied when its internal diode is conducted. So, the main switch turns on under ZVT. After that, the auxiliary switch is turned off under ZCS when its current is fallen to zero due to the resonance.

B. Turning off under ZCT for the Main Switch

Before turning off interval of the main switch, S_1 is at on state and S_2 is at off state. Then, a gate signal is applied the auxiliary switch and a resonance begins between the snubber capacitor C_p and L_{lk}. So, the auxiliary switch turns on under ZCS because of series inductance L_{lk}. After the auxiliary switch current reaches to I_{LF}, the internal diode of the main switch turns on under ZVS. Then, the gate signal of the main switch is removed when its internal diode is conducted. So, the main switch turns off under ZCT. After that, the auxiliary switch is turned off under ZCS when its current is fallen to zero by resonance. Also, the main diode turns on under ZVS after the voltage of C_p reaches to the output voltage. Then, the operation of the converter is finished for a switching period.

III. SIMULATION RESULTS

Simulations are realized on a prototype of the 1 kW PFC ZVZCT boost converter with an active snubber cell for 1 kW and 100 kHz in PSIM program. The simulation parameters and the value of the devices are given in Table I.

TABLE I
THE SIMULATION PARAMETERS AND THE VALUE OF THE DEVICE OF CONVERTER

Output Power (P_o)	1 kW	**Snubber Inductance (L_r)**	5 µH
Switching Frequency (f)	100 kHz	**1:n (L_b)**	1:1.5
AC Input Voltage (V_i)	200 V_{peak}	**Snubber Capacitor (C_r)**	10 nF
DC Output Voltage (V_o)	400 V	**Parasitic Capacitor (C_p)**	1 nF
Main Inductance (L_F)	500 µH	**Output Capacitor (C_o)**	470 µF

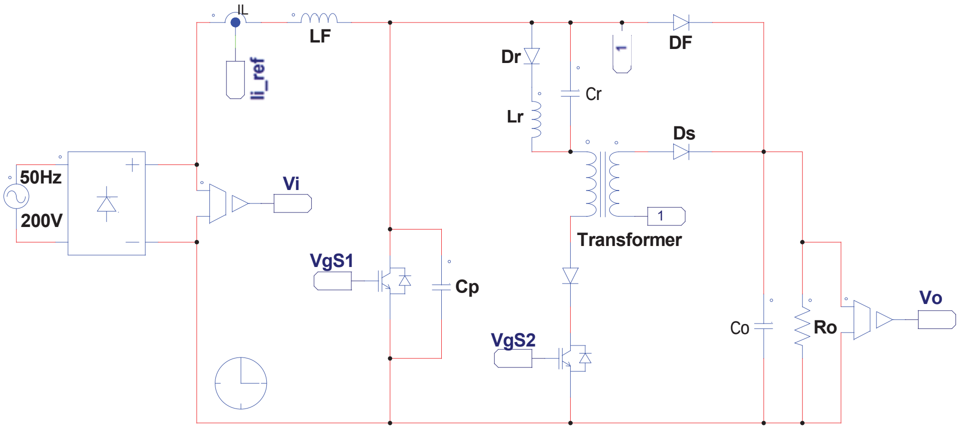

Fig. 2 The simulation circuit scheme of the PFC converter

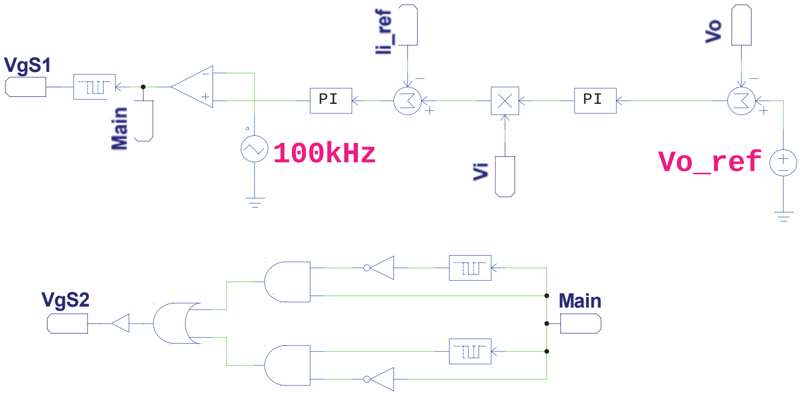

Fig. 3 PFC average current control block scheme for PWM control signals

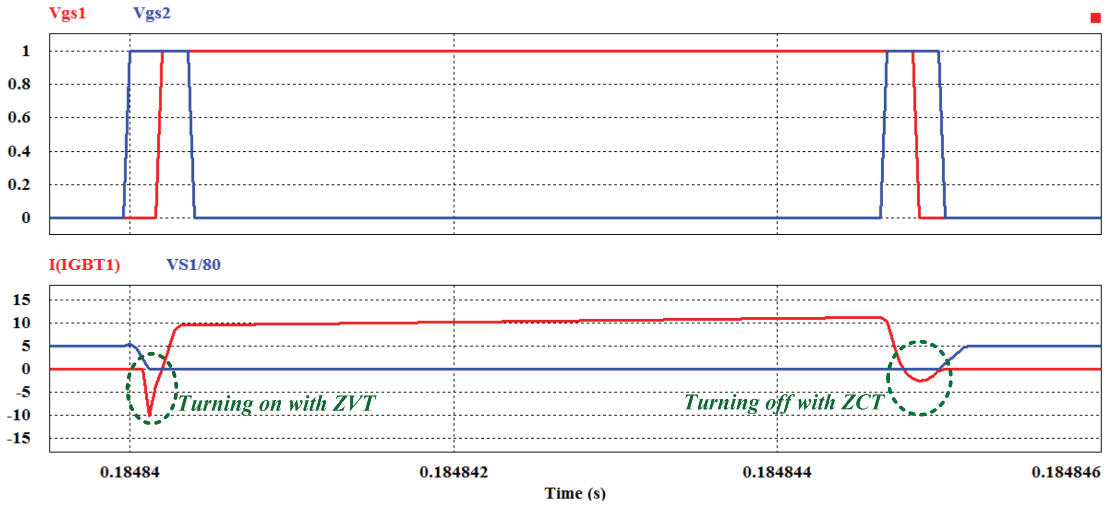

Fig. 4 Respectively; the control signals of main switch and auxiliary switch, the voltage and current of main switch

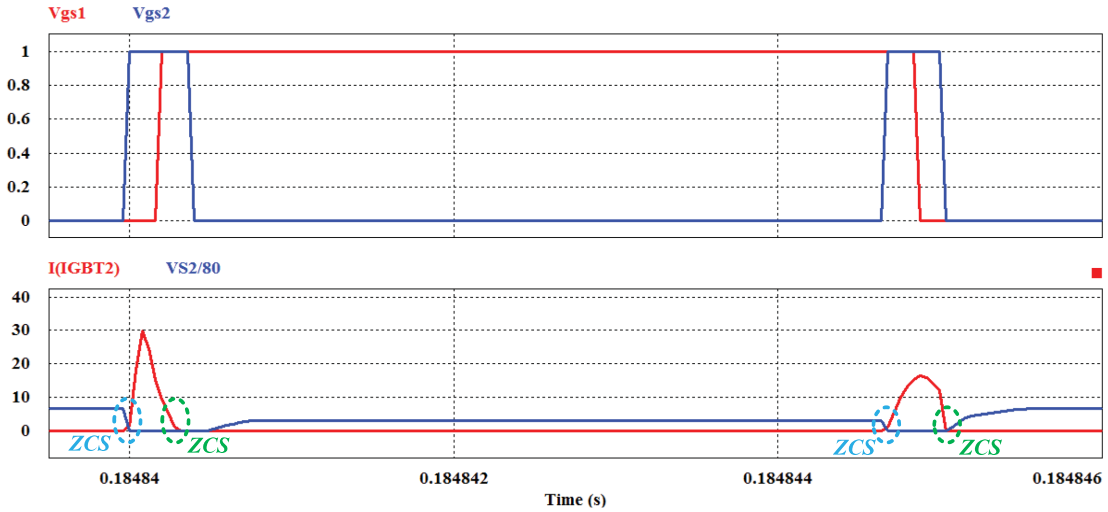

Fig. 5 Respectively; the control signals of main switch and auxiliary switch, the current and voltage of auxiliary switch

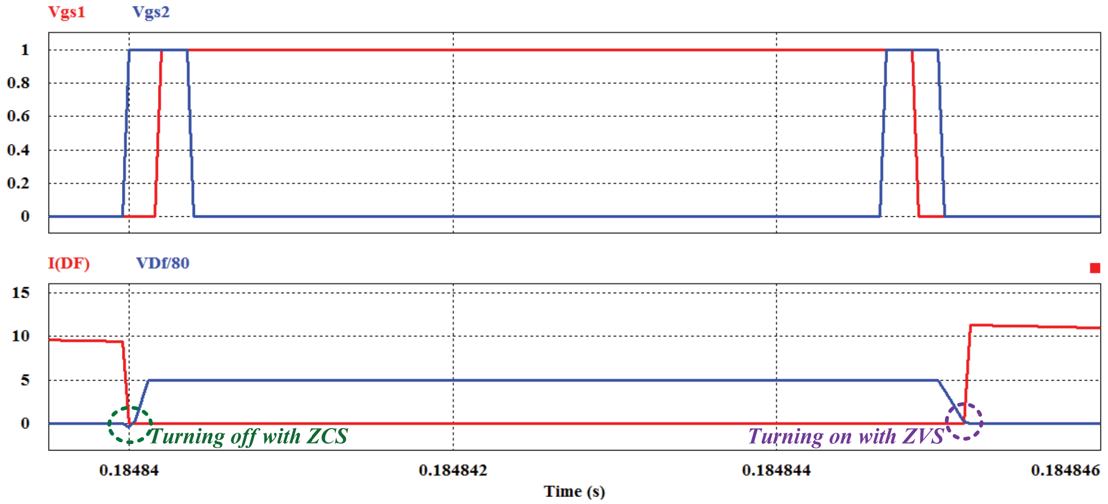

Fig. 6 Respectively; the gate signals of the switches, the current and voltage of the main diode

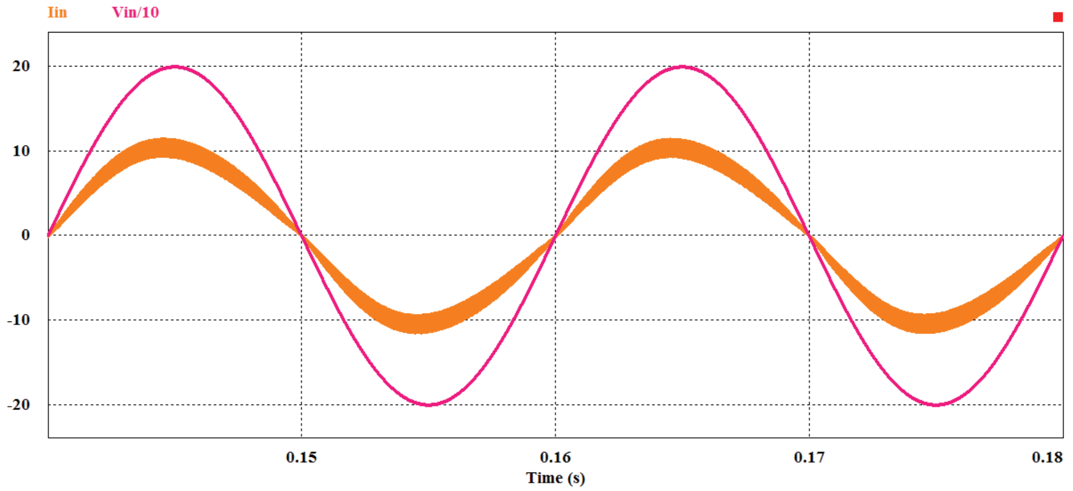

Fig. 7 The input voltage and current waveforms of PFC converter

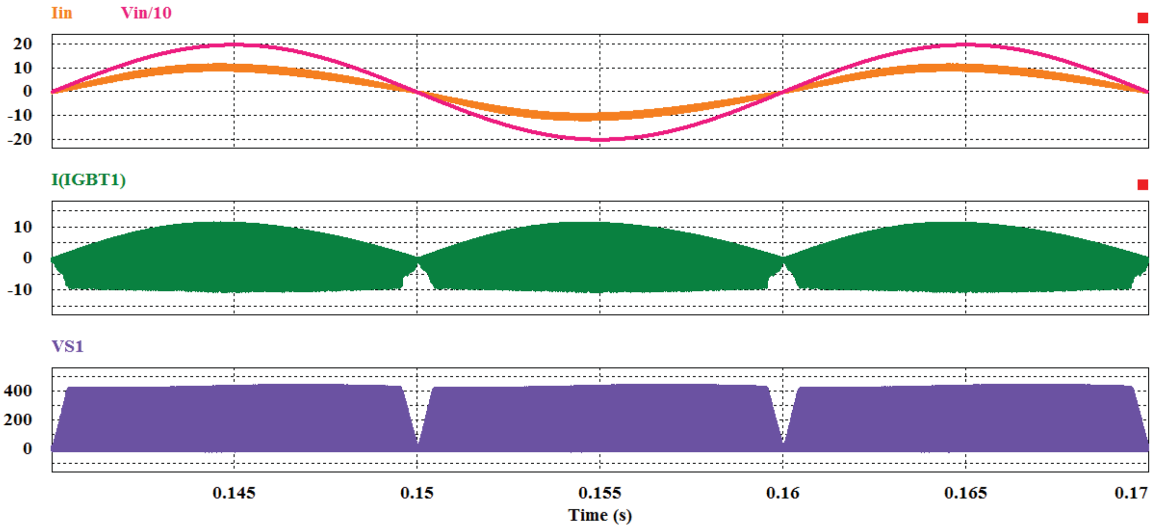

Fig. 8 Respectively; the input voltage and current waveforms of PFC converter, the current waveform and the voltage waveform of the main switch

The simulation circuit scheme of the converter is given in Fig. 2. The gate signals of the switches are obtained with the PFC average current mode controller. The block scheme of the controller is given Fig. 3. The simulation results of the converter are shown in Figs. 4-8. The voltage value of switches is scaled at 1/80 ratio in figures.

The gate signal and current–voltage waveforms of the main switch S_1 are given in Fig. 4. As shown in figure, the voltage of main switch is fallen to zero with the aid of the snubber cell before the main switch is turned on. Then, the main switch turns on under ZVT while the body diode of main switch is on state. For turning off, the current of main switch is fallen to zero with the aid of the snubber cell. Then, the main switch turns off under ZCT while the body diode of main switch is at on state. Moreover, there is no additional voltage or current stress on the main switch during this process.

The gate signal and current–voltage waveforms of the main switch S_2 are given in Fig. 5. As shown in figure, the auxiliary switch turns on and off under ZCS.

The gate signal of the switches and current–voltage waveforms of the main diode D_F are given in Fig. 6. As shown in figure, the main diode turns on under ZVS and turns off under ZCS. Also, it is clear that there is not any voltage and current stress on the main diode.

The input voltage and current waveforms are given in Fig. 7. The power factor of the converter is near unity with 0.99. Also, it is seen that the PFC converter operates in CCM. The converter is tested at universal input line voltage and very wide load ranges. It is observed that it keeps operating under SS conditions successfully for the whole line and load ranges. Also, the input voltage and current waveforms are given together with the voltage and current waveforms of the main switch in Fig. 8. The input voltage value is scaled at 1/10 ratio in Figs. 7 and 8.

IV. CONCLUSIONS

In this paper, 1 kW PFC ZVZCT boost converter with an active snubber cell is given. The snubber cell provides to ZVT

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turning on and ZCT turning off for the main switch. Also, it provides ZVS turning on and ZCS turning off for the main diode. In the converter, there is no extra voltage or current stress on the main devices. The auxiliary switch turns on and turns off under ZCS. However, extra voltage stress occurs on the auxiliary switch. The extra current or voltage stress does not occur on the other auxiliary elements and all of them operate under SW. The most important feature of the converter is that it has direct power transfer feature as well as excellent SS techniques.

The converter solves many drawbacks of the PFC converters presented earlier. All semiconductor devices in the circuit are switched under SW. A steady-state analysis of the converter is presented. The theoretical analysis of the converter is exactly verified by 1 kW and 100 kHz prototype. The average current mode control method is used in the converter. The power factor of the converter is measured nearly as 0.99.

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