A ZVT-ZCT-PWM DC-DC Boost Converter with Direct Power Transfer

Naim Suleyman Ting, Yakup Sahin, Ismail Aksoy

Abstract—This paper presents a zero voltage transition-zero current transition (ZVT-ZCT)-PWM DC-DC boost converter with direct power transfer. In this converter, the main switch turns on with ZVT and turns off with ZCT. The auxiliary switch turns on and off with zero current switching (ZCS). The main diode turns on with ZVS and turns off with ZCS. Besides, the additional current or voltage stress does not occur on the main device. The converter has features as simple structure, fast dynamic response and easy control. Also, the proposed converter has direct power transfer feature as well as excellent soft switching techniques. In this study, the operating principle of the converter is presented and its operation is verified for 1 kW and 100 kHz model.

Keywords—Direct power transfer, boost converter, zero-voltage transition, zero-current transition.

I. INTRODUCTION

DC-DC boost converters are generally used in industrial applications as solar energy, wind turbine systems, electrical vehicles, power factor correction, etc. due to their perfect dynamic performance, high power density and fast transition response. The high power density can be obtained by increasing the switching frequency. But the high switching frequency leads to high switching losses and electromagnetic interference (EMI). So, it decreases the performance and efficiency of the converter. These problems can be solved by using the soft switching (SS) techniques instead of hard switching (HS) techniques. SS techniques are Zero Voltage Switching (ZVS), ZCS, ZVT, and ZCT techniques [1]-[15].

In the fundamental ZVT boost converter [1], main switch turns on with ZVT with the help of an active snubber cell. Many ZVT converters are suggested to solve the problems in basic ZVT converter [3]-[7]. In the fundamental ZCT boost converter [2], the main switch turns off with ZCT with the help of an active snubber cell. Many ZCT converters are suggested to solve the problems in basic ZCT converter [8]-[12]. ZVT-ZCT converters are suggested in order to solve problems in ZVT and ZCT converters. This circuits which are formed by combining the ZVT and ZCT methods, are suggested in [13]-[15].

In this paper, an SS active snubber cell for DC-DC PWM boost converter is proposed. The proposed converter is shown in Fig. 1. In this converter, the main switch turns on with ZVT and turns off with ZCT. The main diode turns on with ZVS and turns off with ZCS. Also, there is no additional current or

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voltage stress on the main devices. The auxiliary switch and the auxiliary diodes both turn on and turn off with ZCS. The proposed converter decreases EMI noises and operates a wide load voltage range.
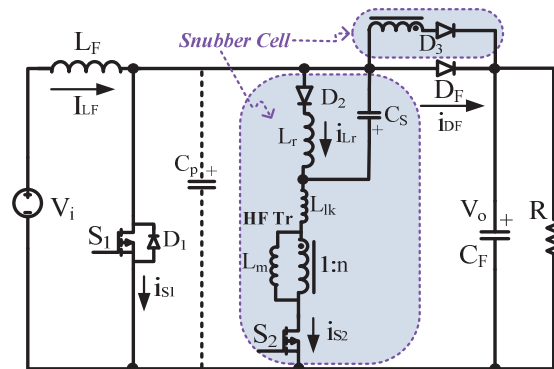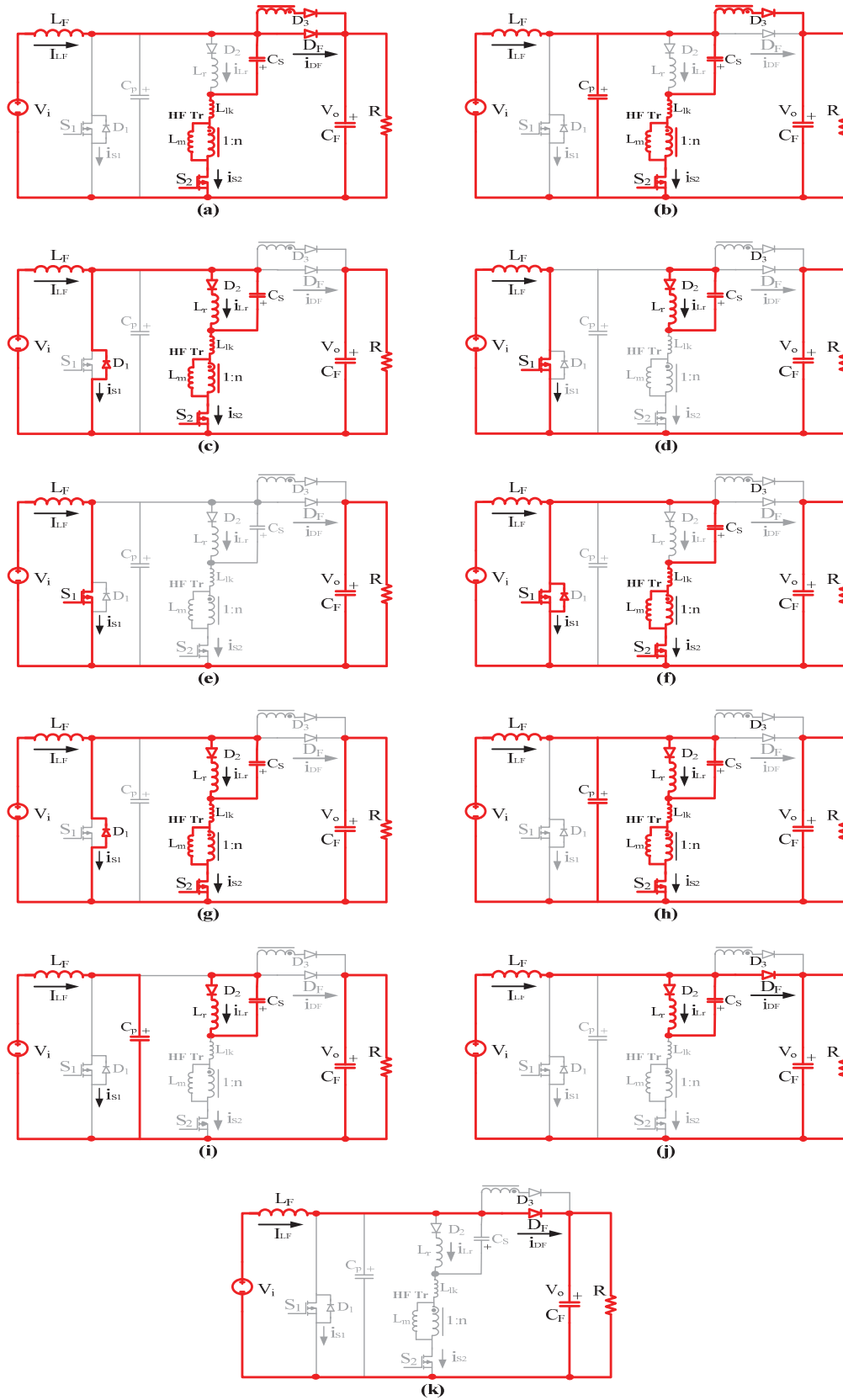

Fig. 1 The basic circuit scheme of the proposed converter

II. OPERATING INTERVALS OF THE PROPOSED CONVERTER

The circuit scheme of the proposed ZVT-ZCT-PWM DC-DC boost converter with direct power transfer is given in Fig. 1. In this converter, V_i is DC input voltage, V_o is the output voltage, L_F is the main inductance, C_F is the output capacitor, R is the resistive load, S_1 is the main switch, C_p is the sum of the parasitic capacitors of the main switch and the others, D_1 is the internal diode of the main switch and D_F is the main diode. In the snubber circuit of the converter, S_2 is the auxiliary switch, L_r is snubber inductance, L_{lk} is the leakage inductance and L_m is magnetization inductance of transformer, C_s is the snubber capacitor, D_2 and D_3 are the auxiliary diodes.

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

- Output voltage V_o and input current I_i are constant for one switching cycle.
- All semiconductor devices and resonant circuits are ideal.
- The reverse recovery times of all diodes are not taken into account.

Eleven intervals occur in the steady state operation in a switching cycle. The equivalent circuit schemes of the operation intervals are shown in Figs. 2 (a)–(k), respectively.

Fig. 2 Equivalent circuit of the operating intervals in proposed converter

A. Interval 1 [$t_0 < t < t_1$: Fig. 2 (a)]

Before $t = t_0$, the switches S_1 and S_2 are at off state. The main diode D_F conducts the input current I_i. At $t = t_0$, a control signal is applied to auxiliary switch and then, the main diode current decreases while the auxiliary switch current and the snubber capacitor C_s voltage increase.

At $t = t_1$, the main diode current falls to zero when the auxiliary switch current reaches to input current I_i. So, the auxiliary switch S_2 turns on and the main diode D_F turns off with ZCS due to series inductor.

B. Interval 2 [$t_1 < t < t_2$: Fig. 2 (b)]

In this interval, a resonance begins between parasitic capacitor C_p and the snubber cell. Thus, the voltage of C_p decreases while the auxiliary switch current and the voltage of C_s are increasing. Here, the energy of C_p is transferred to the primer inductor of transformer and the primer inductor transfers the part of energy to the output load.

At $t = t_2$, D_1 diode turns on with ZVS when the voltage of C_p falls to zero and the auxiliary switch current reaches to maximum value. Then, this interval ends.

C. Interval 3 [$t_2 < t < t_4$: Fig. 2 (c)]

At $t = t_2$, a new resonance starts via L_{lk}-L_r-C_s and the energy of the transformer primer inductor is transferred to L_r and C_s. It is called ZVT interval where D_1 is at on state. A control signal is applied to the main switch S_1 in this interval. In this way, the main switch turns on as lossless with ZVT.

At $t = t_3$, the current of transformer primer inductor falls to the input current level and D_1 diode turns off with ZCS. After that, the current of the main switch increases while current of transformer primer inductor continues to decrease.

At $t = t_4$, the current of transformer primer inductor falls to zero when the current of main switch reaches to input current level. So, the auxiliary switch turns off with ZCS and this interval ends.

D. Interval 4 [$t_4 < t < t_5$: Fig. 2 (d)]

During this interval, the energy stored in snubber inductance L_r is transferred to capacitor C_s via L_r-C_s-D_2 resonance. At $t = t_5$, the voltage of C_s reaches to maximum value in adverse direction and the current of L_r falls to zero. Then, this interval ends.

E. Interval 5 [$t_5 < t < t_6$: Fig. 2 (e)]

This interval is equal to basic boost converter and the main switch S_1 passes to the input current I_i. At $t = t_6$, a control signal is applied to the auxiliary switch S_2 and it turns on with ZCS due to series inductor L_{lk}. Then, this interval ends.

F. Interval 6 [$t_6 < t < t_8$: Fig. 2 (f)]

At $t = t_6$, a resonance starts between the snubber capacitor C_s and the transformer primer inductor after the auxiliary switch is turned on. The main switch current begins to decrease while the current of primer inductor is increasing.

At $t = t_7$, the current of S_1 falls to zero when the current of primer inductor reaches to the input current level. So, D_1 turns on with ZCS and it conducts the excess of input current. This

interval is called ZCT interval where D_1 is at on state. The control signal of the main switch S_1 is removed in this interval. In this way, the main switch S_1 turns off as lossless with ZCT.

At $t = t_8$, the current of primer inductor reaches to maximum value when the voltage of C_s falls to zero. Then, this interval ends.

G. Interval 7 [$t_8 < t < t_9$: Fig. 2 (g)]

At $t = t_8$, a new resonance starts via L_{lk}-L_r-C_s and the energy of the transformer primer inductor is transferred to L_r and C_s. At $t = t_9$, D_1 turns off when the current of primer inductor falls to the input current level and this interval ends.

H. Interval 8 [$t_9 < t < t_{10}$: Fig. 2 (h)]

In this interval, a resonance occurs between C_p and snubber cell with the constant input current. The current of L_r and the voltage of C_s increase while the current of transformer primer inductor decreases.

At $t = t_{10}$, the current of primer inductor falls to zero and the control signal of S_2 is removed. So, S_2 turns off with ZCS and this interval ends.

I. Interval 9 [$t_{10} < t < t_{11}$: Fig. 2 (i)]

In this interval, two discrete circuits happen. The parasitic capacitor C_p is linearly charged with the constant input current and the energy stored in L_r is transferred to the C_s with resonance.

At $t = t_{11}$, the voltage of C_p reaches to the output voltage and so, the main diode D_F turns on with ZVS. Then, this interval ends.

J. Interval 10 [$t_{11} < t < t_{12}$: Fig. 2 (j)]

In this interval, the resonance between L_r and C_s continues. The energy of L_r is transferred to C_s. At $t = t_{12}$, the current of L_a falls to zero and this interval ends.

K. Interval 11 [$t_{12} < t < t_{13}$: Fig. 2 (k)]

In this interval, the main diode D_F is at on state and the input voltage source supplies to the output load. This interval is basic PWM boost converter turned off interval. Thus, it is returned to initial conditions and the intervals expressed is repeated in the next switching cycle.

III. SIMULATION RESULTS

TABLE I
THE SIMULATION PARAMETERS AND THE DEVICE VALUES OF PROPOSED CONVERTER

Output Power (P_o)	1 kW	Snubber Inductance (L_r)	5 µH
Frequency (f_s)	100 kHz	1:n (L_b)	1:1.5
Input Voltage (V_i)	200 V	Snubber Capacitor (C_s)	4.7 nF
Output Voltage (V_o)	400 V	Parasitic Capacitor (C_p)	1.5 nF
Main Inductor (L_F)	1mH	Output Capacitor (C_o)	47 µF

It is realized a prototype of the proposed ZVT-ZCT-PWM DC-DC boost converter with direct power transfer for 1 kW and 100 kHz in PSIM program. The simulation parameters and the value of the devices are given in Table I. The simulation

circuit scheme of the proposed converter is given in Fig. 3. The
simulation results of the converter are shown in Figs. 4-7.
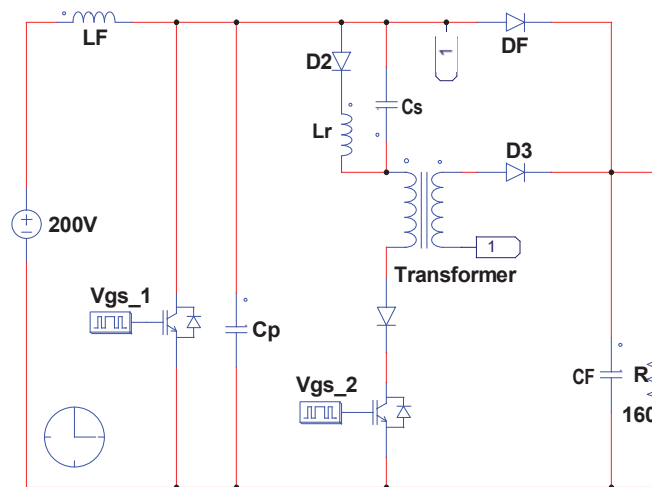

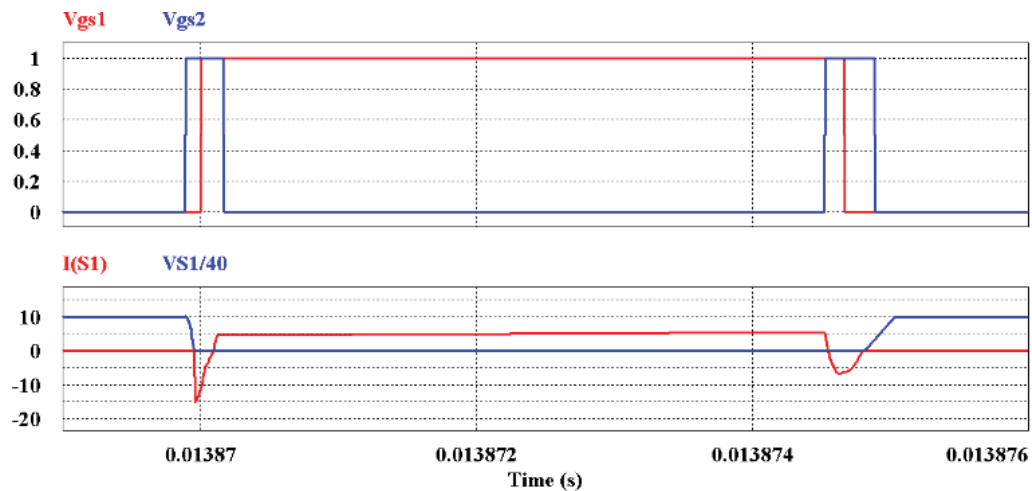Fig. 3 The simulation circuit scheme of the proposed converter

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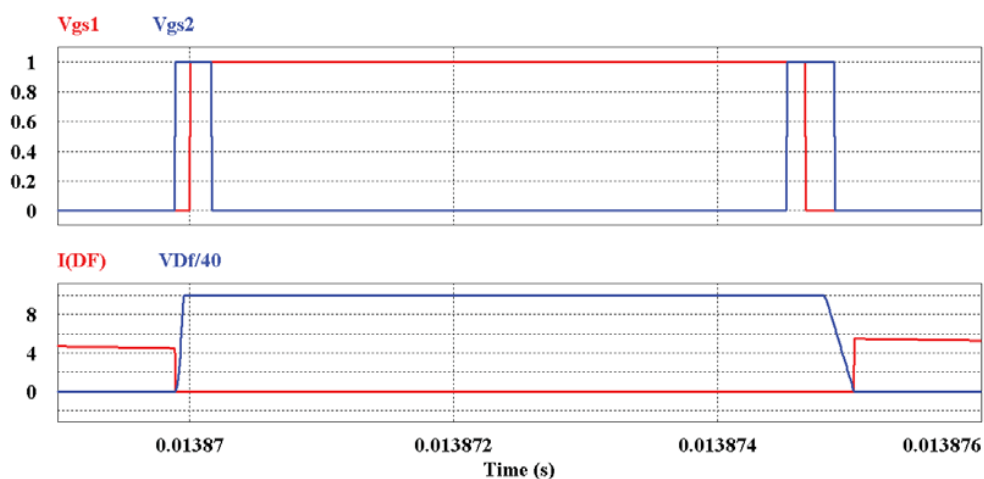

Fig. 5 Respectively; the control signals of the switches, the current and voltage of the main diode
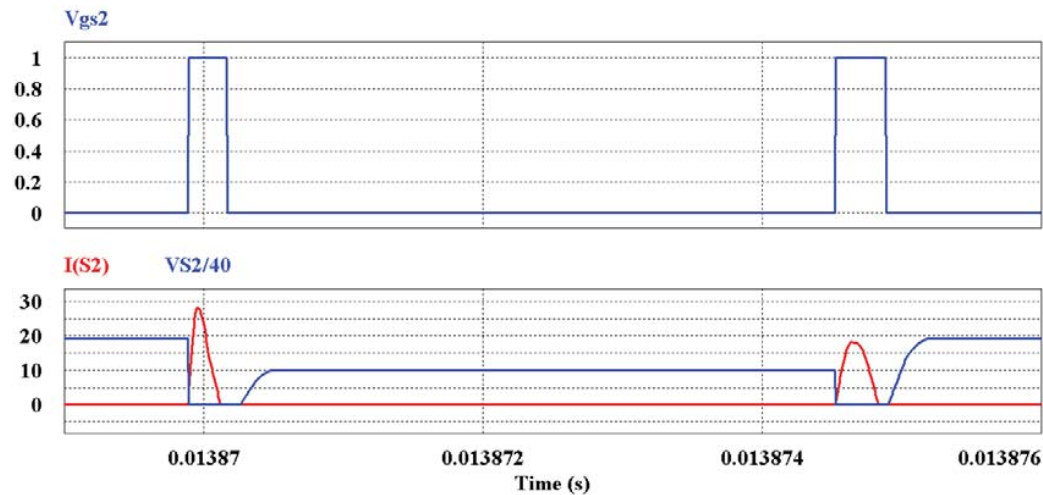
Fig. 6 Respectively; the control signal of auxiliary switch, the voltage and the current waveform of the auxiliary switch
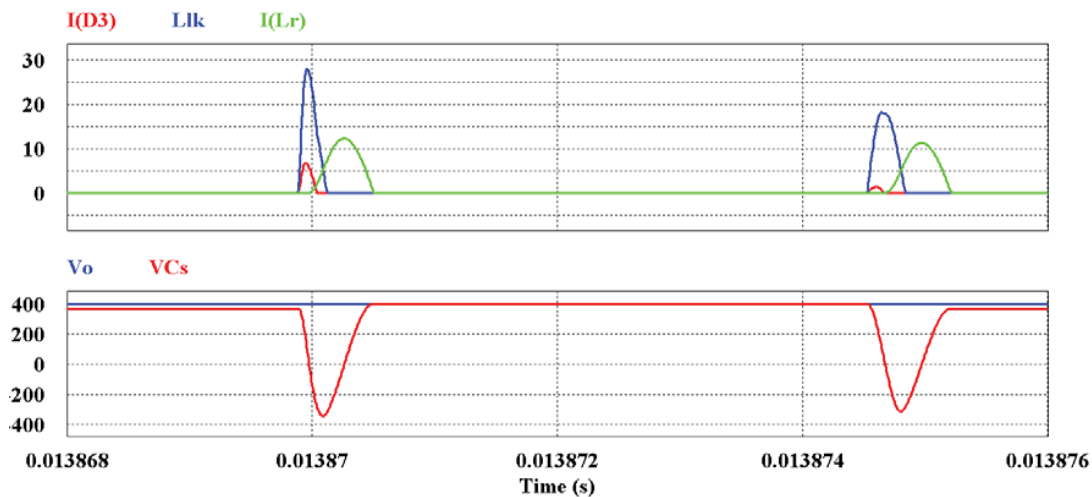

Fig. 7 Respectively; the voltage waveforms of C_s, the current of L_r, the current of primer and seconder transformer

The simulation current and voltage waveforms of the main switch are given in Fig. 4. The voltage of main switch is fallen to zero before the main switch is turned on. Then, the main switch turns on with ZVT while the body diode of main switch conducts. Likewise, the current of main switch is fallen to zero before the main switch is turned off. Then, the main switch turns off with ZCT while the body diode of main switch conducts. Also, it is seen that there is not any voltage or current stress on the main switch.

The current and the voltage waveforms of main diode are given in Fig. 5. As shown in figure, the main diode turns on with ZVS and turns off with ZCS. Also, it seems that there is not any voltage and current stress on the main diode.

The control signals of the main switch and the auxiliary switch, the current – voltage waveforms of the auxiliary switch are shown in Fig. 6. As shown in figure, the auxiliary switch turns on with ZCS and turns off with ZCS.

The voltage waveforms of C_s, the current of L_r, the current of primer and seconder transformer are shown in Fig. 7. As

shown in figure, the voltage of C_s capacitor does not exceed to the output voltage. Also, direct power transfer to the output load is provided by transformer.

IV. CONCLUSIONS

In this paper, a ZVT-ZCT-PWM DC-DC boost converter with direct power transfer is proposed. In this converter, the main switch turns on with ZVT and turns off with ZCT. The main diode turns on with ZVS and turns off with ZCS. The auxiliary switch turns on and off with ZCS. The auxiliary diodes operate with SS. There is no additional voltage or current stress on the main devices. The proposed converter decreases EMI noise and operates even in light load conditionals.

In the proposed converter, the snubber cell has simple structure and ease of control because of common ground. Also, this converter has some advantages as low cost, high power density. In here, the switching power losses are eliminated and EMI noises are reduced by the proposed

snubber cell. A detailed steady-state analysis of the proposed converter is presented. The theoretical analysis of the proposed converter is exactly verified by 1 kW and 100 kHz prototype.

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