Analysis and Simulation of Novel Soft Switching High Frequency Boost Converter

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***Abstract-* This paper presents the analysis and simulation of a new type of soft switching boost converter used for high frequency applications. It has an active snubber cell that provides main switch to turn ON with zero voltage transition and to turn OFF with zero current transition. The proposed converter can be operated at high frequencies. In this converter all semiconductor devices operating under soft switching. Also in this converter, there is no additional voltage stress across the main and auxiliary components. Also a modified soft switching converter is also given in this paper. That can be used for ac voltage applications and it can be extended to be used in LED lighting applications. The operation, design and analysis of this PWM boost converter and simulation of new topology is also given in this paper.**

Index Terms*—Boost converter, soft switching, zero voltage switching(ZVS), zero current switching(ZCS), zero voltage transition(ZVT), zero current transition(ZCT)

I.INTRODUCTION

High frequency PWM DC-DC converters are generally used in renewable energy applications, battery charging, lighting applications and power factor correction due to their fast response and high power density. To achieve high power density and small converter size, it is required to operate converter at high switching frequency. But high frequency operation results in increased switching losses, high converter efficiency and higher electromagnetic interference. By using soft switching all these disadvantages can be minimized. Soft switched resonant dc-dc power converters are able to maintain high efficiency for increased switching frequency[1].

In this paper, a new type of boost converter with active snubber cell is proposed. In this converter, the main switch turn ON with ZVT and turn OFF with ZCT. Also, in this converter, all the semiconductor devices operate under soft switching. The proposed converter also have a simple structure and it is of low cost[2]. Following the introduction, the system configuration is given in section II. Section III describes the operation modes of the converter. In section IV, a deeper analysis of the converter is presented. Section V provides simulation results to validate the analysis. Finally, conclusions are given in section VI.

II. SYSTEM CONFIGURATION

The system configuration of the soft switching high frequency boost converter is depicted in Fig.1.

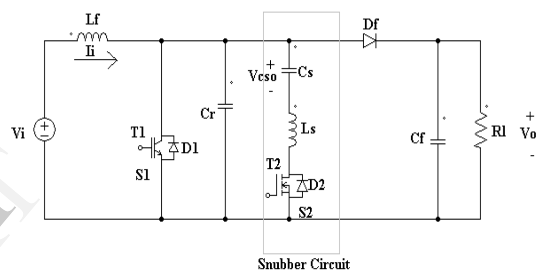
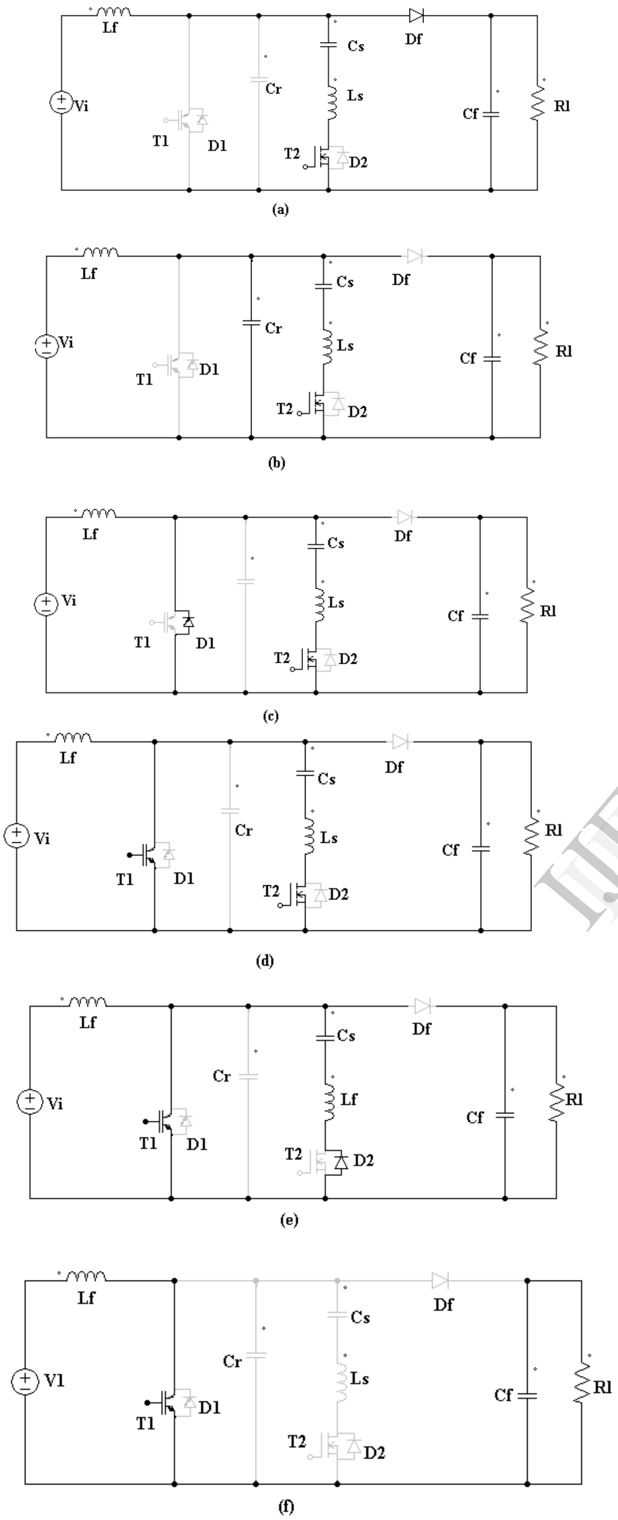


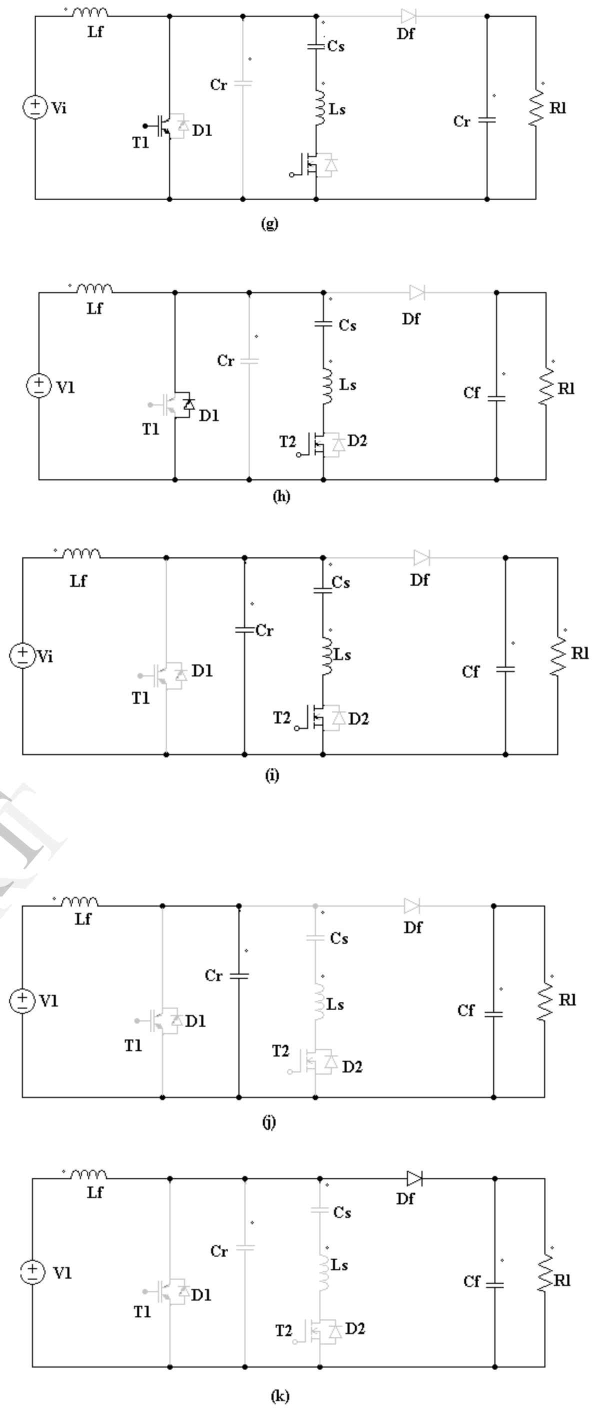
Fig.1.Circuit diagram of the proposed Converter

In this circuit V_i is the input voltage, L_f is the main inductor, S_1 is the main switch, S_2 is the auxiliary switch, D_f is the main diode, C_f is the output filter capacitor, C_s is the snubber capacitor, C_r is the parasitic capacitor, L_s is the snubber inductor and V_o is the output voltage. The main switch S_1 consist of the main transistor T_1 (IGBT) and body diode D_1. The auxiliary switch S_2 consist of transistor T_2 (MOSFET) and body diode D_2. Here the parasitic capacitor C_r is assumed to be the sum of the parasitic capacitor of S_1 and the other parasitic capacitors incorporating it.

During one switching cycle, the following assumptions are made. The input and output voltages and input current are assumed to be constant and the reverse recovery time of D_f is taken into account. The semiconductor devices and resonant circuit are assumed to be ideal for simplification.

III. OPERATION MODES





Operation modes of the proposed soft switching boost converter. (a)mode 1; (b)mode 2; (c)mode 3; (d)mode 4; (e)mode 5; (f) mode 6; (g) mode 7; (h) mode 8; (i) mode 9; (j) mode 10; (k) mode 11

Mode 1: At the beginning of this mode, the main transistor T_1 and auxiliary transistor T_2 are in the off state. The main diode

D_f is in the ON state and let the beginning of mode 1 be the OFF state of the conventional boost converter. Let the input current I_i flows through the main diode. So in the beginning, I_{T_1} =0; I_{Ls} =I_{T2} =0; I_{Df} =I_i; and I_{Df} =V_o.

The mode 1 begins by applying a turn on signal to the gate of the auxiliary transistor T_2. Now a resonance starts between the snubber inductance L_s and the snubber capacitance C_s. Due to the resonance, T_2 current rises and D_f currents falls simultaneously. The rate of rise of the T_2 current is limited by the snubber inductance L_s that connected in series with the auxiliary switch. So the turn on of the auxiliary switch provided with ZCS. At the end of this mode, the snubber capacitance voltage V_{Cs} charged to V_{Cs_1}. i_{T2} reaches I_i and I_{Df} falls to zero. When I_{Df} reaches -I_{rr}, D_f is turned OFF and this stage finishes. So in mode 1, T_2 turns on with zero voltage switching and D_f turned OFF with nearly zero voltage switching and zero current switching.

Mode 2: At the beginning of this mode, I_{T_1} =0; I_{Ls} =I_{T2} = I_i+I_{rr}; I_{Df}=0; V_{Cr} =V_o and V_{Cs} =V_{Cs_1}. The main diode D_f and main transistor T_1 are in the OFF state. The auxiliary transistor T_2 is in the ON state and that conduct the sum of the input current I_i and the reverse recovery current of D_f .

This mode begins with a resonance between the parasitic capacitor C_r, snubber capacitance C_s and the snubber inductance L_s. This mode finishes with the parasitic capacitance voltage V_{Cr} becomes 0.Thus the energy stored in the parasitic capacitor C_r will be completely transferred to the resonance circuit. At the end of this mode, diode D_1 turns ON with nearly zero voltage switching. At the end of this mode, V_{Cs}=V_{Cs_2}.

Mode 3: Just after the diode D_1 turned ON, i.e. at the beginning of this mode, I_{T_1}=0; I_{Ls}=I_{T2}=I_{Ls_2}, I_{Df}=0, V_{Cr} =0 and V_{Cs}=V_{Cs_2}.

In this mode, the resonance between the snubber inductance L_s and the snubber capacitance C_s continuous. Here the diode D_1 is turned ON and that will conduct the excess of the snubber inductance current from the input current. This interval is called the ZVT duration of the main transistor. At the end of this mode, a control signal is applied to the gate of the main transistor T_1. The diode D_1 is kept turned ON in order to provide ZVT turn On of T_1.This mode ends with the snubber inductance current falls to input current and the diode D_1 turned OFF under ZCS.

Mode 4: This mode begins when the diode D_1 is turned OFF. At the beginning of this mode, I_{T_1}=0, I_{Ls}=I_{T2}=I_{Ls_3}=I_i, I_{Df}=0, V_{Cr} =0 and V_{Cs}=V_{Cs_3}.

The main transistor T_1 turns ON with ZVT and its current starts to rise. The resonance between snubber inductance L_s. and snubber capacitor C_s continuous. At the end of this mode, the main transistor current reaches to Ii and I_{Ls} becomes z0ero. this mode ends by removing the control signal of the auxiliary transistor.

Mode 5: At the beginning of this mode, the auxiliary transistor T_2 is turned OFF under ZCT. And at the beginning, I_{T_1} =I_i, I_{Ls}=I_{T2}=I_{LS4}=0, V_{Cs} =V_{Cs_4}, V_{Cr} =0 and I_{Df}=0.

This mode begins with the turn ON of the diode D_2 with zero current switching and its current starts to rise. The resonance between snubber inductance L_s and snubber capacitance C_s continuous in this mode. I_{Ls} become negative and the current through the main transistor current becomes higher than the input current. At the end of this mode, the main transistor current decreases to input current level and I_{Ls} becomes zero. Then I_{D2} becomes 0 and D_2 turned OFF under ZCS at the end of this mode.

Mode 6: At the beginning of this mode, I_{T_1} =I_i, I_{Ls}=I_{T2}=I_{Ls_4}=0, I_{Df}=0, V_{Cs} =V_{Cs_5} and V_{Cr} =0.

In this mode, the main transistor continuous to conduct the input current Ii and in this case, the snubber circuit is not active. This mode can be stated as the ON state of the conventional boost converter. The ON state duration can be controlled by the PWM control.

Mode 7: At the beginning of this mode, I_{T_1} =I_i, I_{Ls}=I_{T2}=0, I_{Df}=0, V_{Cs} =V_{Cs_6} and V_{Cr} =0.

This mode begins by applying a control signal to the gate of the auxiliary transistor T_2. Then a new resonance between snubber inductance L_s and snubber capacitor C_s starts. In this mode, the auxiliary transistor T_2 turned ON with ZCS. At the end of this mode, the current through the auxiliary transistor current reaches input current level and the main transistor current becomes zero.

Mode 8: At the beginning of this mode, I_{T_1} =0, I_{Ls}=I_{T2}=I_i, I_{Df}=0, , V_{Cs} =V_{Cs_7} and V_{Cr} =0.

This mode begins when T_1 current falls to zero so that D_1 turns ON with ZCS. T_1 can be turned OFF after the turn ON of D_1so that T_1 can be turned OFF under ZCS and ZVS. The resonance between L_s and L_s continuous in this mode also. This mode ends by the turn OFF of D_1.

Mode 9: This mode begins after the turn OFF of D_1 under ZCS. At the beginning of this mode, I_{T_1} =0, I_{Ls}=I_{T2}=I_{Ls_8}=$I_i - I_{rr}$, I_{Df}=0, V_{Cs} =V_{Cs_8}=V_{Cs_0} and V_{Cr} =0.

Now a resonance between parasitic capacitor C_r, snubber inductance L_s and snubber capacitor C_s starts and I_{Ls} falls to zero and the capacitor C_r charged from 0 to V_{Cs_8}. At the end of this mode, the control signal from the auxiliary transistor T_2 is removed. So that, T_2 is turned OFF under ZCS.

Mode 10: At the beginning of this mode, I_{T_1} =0, I_{Ls}=I_{T2}=I_{Ls_9}=0, I_{Df}=0, V_{Cs}=V_{Cs_9}=V_{Cs_0} and V_{Cr}=V_{Cs_8}.

During this mode, the parasitic capacitor C_r is charged linearly under the input current. At the end of this mode, voltage across C_r reaches the output voltage V_o and the main diode D_f is turned ON under ZVS. This mode finishes.

Mode 11: At the beginning of this mode, I_{T_1} =0, I_{Ls}=I_{T2}=0, I_{Df}=I_i, V_{Cs}=V_{Cs_0} and V_{Cr}=V_o.

This mode can be stated as the OFF state of the conventional boost converter. During this mode, the main diode D_f continuous to conduct the input current I_i, and the snubber circuit is not active. The duration of this mode can be controlled by the PWM control. This is the end of one switching cycle. After this another switching cycle starts.

IV.SIMULATUON RESULTS

First conventional hard switching boost converter simulation is performed with input voltage Vin = 12V, output voltage Vo = 28V, output power Po = 100W and switching frequency of main switch f_1 = 100 kHz .Fig 3. Shows the PSIM schematic layout of this hard switching boost converter.

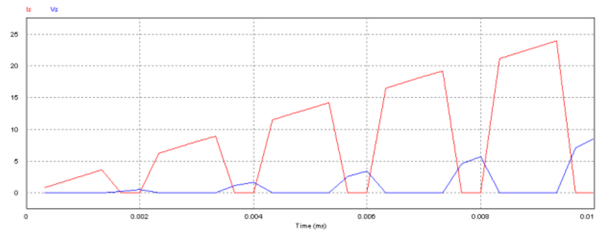


Fig.6. Voltage and Current waveform across the main switch

From the results, we understood that the losses across the main switch is very high. So a new snubber circuit is introduced to reduce the switching losses by employing zero voltage and zero current transition across the main and auxiliary switches and the main diodes. So the switching losses can be reduced by reducing the overlap between the voltage and current waveforms across the switches.

The performance of the high frequency soft switching boost converter with zero voltage and zero current transition was evaluated and simulated a with following specification using PSIM software: input voltage Vin = 12V, constant output voltage of Vo = 28V, output power Po = 100W, switching frequency of main switch f_1 = 100 kHz and switching frequency of auxiliary switch f_2 = 100 kHz. Fig.3 shows the PSIM schematic layout of this converter. Simulation results are illustrated in Fig. 7 to Fig.10.

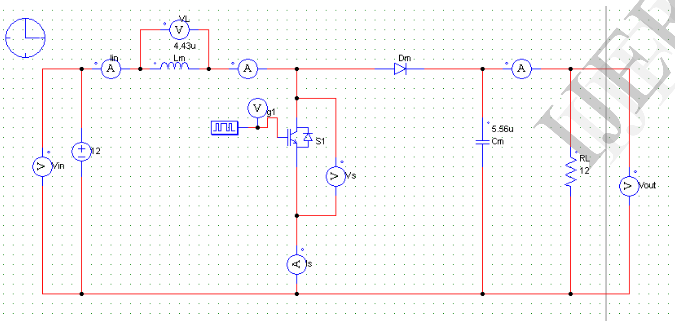


Fig.3. Circuit layout of hard switching boost converter in PSIM

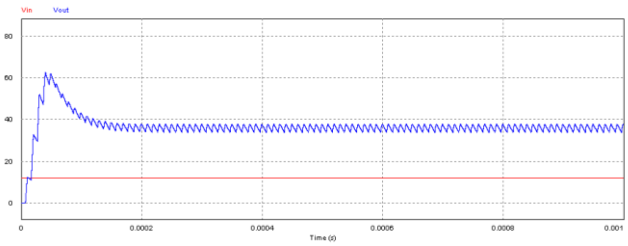


Fig.4. Input and Output voltages

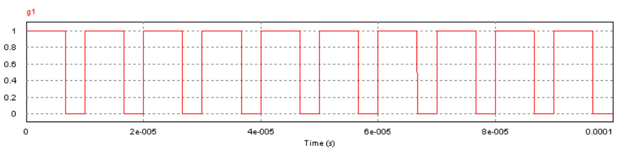


Fig.5. Switching pulse of main Switch

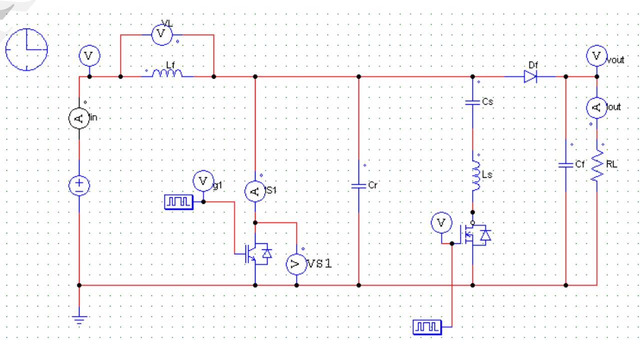


Fig.7. Circuit layout of soft switching boost converter in PSIM

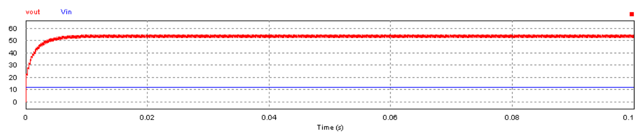


Fig.8. Input and Output voltage waveforms

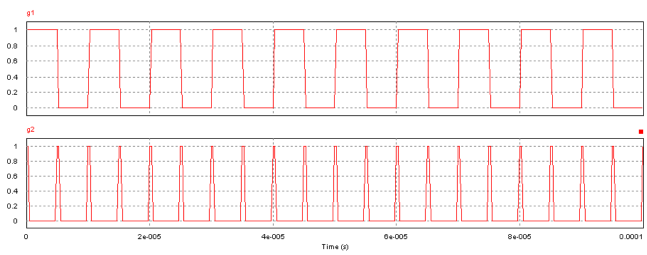


Fig.9. Gate signals of main and auxiliary transistors

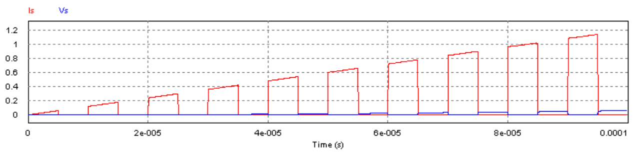


Fig.10. Voltage and Current waveform across main switch

From the simulation results, we can see that the overlap between the voltage and current waveform is reduced. So the switching losses also reduced. So the efficiency is also increased in this converter. So zero voltage and zero current transition can reduces the switching losses.

A new topology is also introduced to work with ac voltage also. It is employed with soft switching to reduce switching losses across the main and auxiliary switches and other semiconductor devices also. It can be extended to use in the brightness control of LED lights.

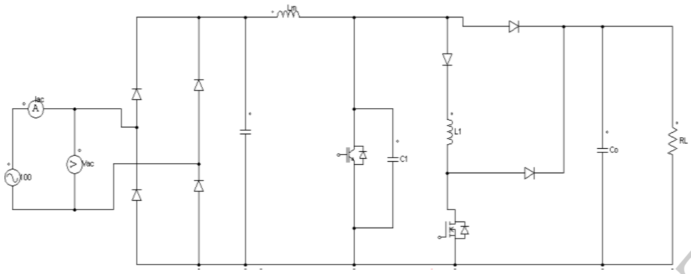


Fig.11. Circuit layout of new topology

Here a rectifier section is used to convert the input ac voltage into dc voltage. That dc can be boosted up using the soft switching boost converter. Soft switching can reduces the switching losses and thus can increase the efficiency.

Simulation of the new soft switching topology is also given below. Simulation results are given from figure 12 to 16.

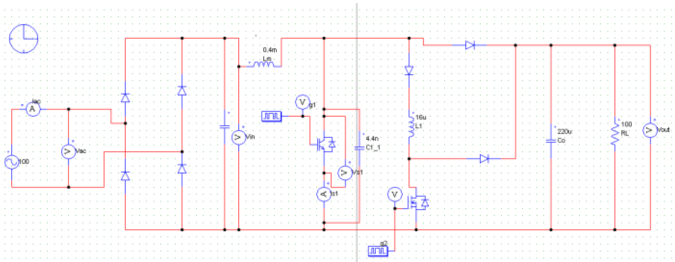


Fig.12. Circuit layout of new topology in PSIM

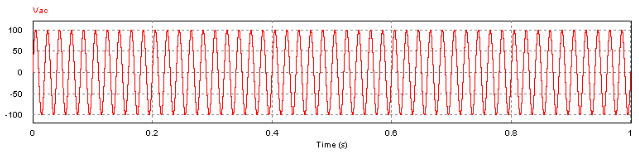


Fig.13. input ac voltage waveform

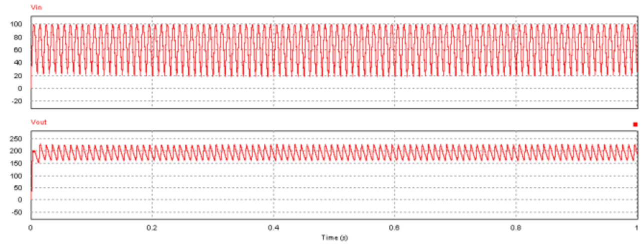


Fig.14.Input and Output voltage waveforms

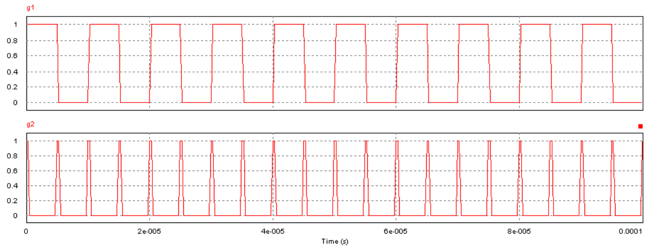


Fig.15. gate pulses of main and auxiliary switches.

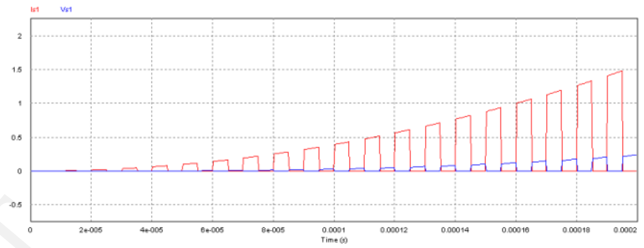


Fig.16. Voltage and Current waveform across main switch

VI.CONCLUSION

In this study, a new type of soft switching boost converter operating under high frequency is analyzed in detail. It has an active snubber cell that provide ZVT turn ON and ZCT turn OFF together for the main switch of the converter. The proposed converter has low cost and complexity. It can be used for high frequency applications. In this converter all semiconductor devices operating under soft switching and there is no additional voltage stress across the main and auxiliary switches. Its operating modes are also analyzed in this study. A new topology of soft switching boost converter that can be used for ac voltage and LED lighting applications are also introduced in this paper. Its simulation in PSIM is also presented.

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