

High Frequency Soft Switching Of PWM Boost Converter Using Auxiliary Resonant Circuit

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ABSTRACT

This thesis presents High frequency Soft Switching DC-DC boost Converter. The circuit consists of a general Boost Converter with an additional resonant circuit which has a switch, inductor, capacitor and a diode. In general Boost Converter circuits have snubber circuits where switching losses are dissipated in external passive resistors; which is known as hard switching. As the switching frequency of PWM converters is increased its switching losses and conduction losses also increases. This restricts the use of PWM technique. New Zero Voltage Transition-Zero Current Transition (ZVT-ZCT) PWM converter equipped with the snubber provides the most desirable features of both ZVT and ZCT converters presented previously. Moreover all semiconductor devices operate with soft switching and hence losses are reduced.

Keywords - Active snubber, ZCS, ZCT, Boost Converter, ZVS and ZVT.

I. INTRODUCTION

Nearly all electronic goods require DC power to run and it is easy to produce from AC-DC converters. However, after that process another DC-DC converter is required for fast and easy Control with high reliability. Fast control needs high switching frequency for the converter. High switching frequency also causes electromagnetic interference (EMI) and extra switching losses [1]. Normally current and voltage waveforms overlap in every switching action which is called hard switching. Addition to overlap power loss at hard switching, reverse recovery loss of diodes and parasitic capacitance discharge loss of the main switch is taken into account for general power loss in switching process. Nowadays, to overcome these drawbacks, soft switching techniques are used. Soft switching techniques provide high efficiency due to lowered or destroyed current or voltage stresses [1-13].

There are mainly four soft switching techniques which are zero current transition (ZCT), zero voltage transition (ZVT), zero current switching (ZCS) and zero voltage switching (ZVS). For ZCT and ZVT techniques power loss can be gained back again, however for ZCS and ZVS techniques only power loss can be lowered.

The proposed converter in [7], main switch ZVT turn on and ZCT turn off, auxiliary switch ZCS turn on and ZCT turn off are provided. Although ZVT-ZCT soft switching techniques improve the efficiency, the current stress on the main switch is two times more than the input current. Nevertheless, extra current stress is present on the auxiliary switch. Because, these extra current stresses affects converter reliability and performance, the system efficiency is

98,3% at full load.

The aim of this study is to improve PWM DC-DC boost converter topology with ZVT-ZCT soft switching techniques. As presented in here, the published converters have extra current and/or voltage stresses even if they use soft switching techniques. So, a new active snubber cell is proposed to solve these problems. In the proposed active cell, main switch ZVT turn on and ZCT turn off, auxiliary switch ZCS turn on and ZCT turn off are provided respectively. The main switch extra current and voltage stresses are eliminated. The auxiliary switch voltage stress is eliminated and current stress is lowered by the coupling inductances in the snubber cell.

II. CONVENTIONAL PWM BOOST CONVERTER

The basic schematic diagram for a PWM boost converter is shown in Fig. 1. The key principle that drives the boost converter is the tendency of an inductor (L_F) to resist changes in current. When being charged it acts as a load and absorbs energy, when being discharged, it acts as an energy source. The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages. The circuit consist of input voltage (V_i) and output voltage (V_o) with main diode (DF). The inductor is charged and discharged by MOSFET switch (T1) which turn on and off according to gate pulse.

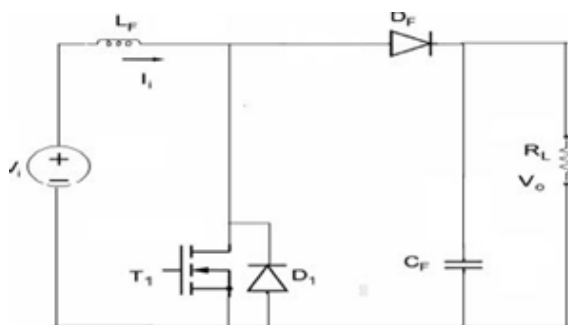


Figure 1. PWM Boost Converter

A. Continuous mode of operation

When a boost converter operates in continuous mode, the current through the inductor (IL) never falls to zero. Fig. 2 shows the typical waveforms of currents and voltages in a converter operating in this mode. The output voltage can be calculated as follows, in the case of an ideal converter operating in steady conditions.

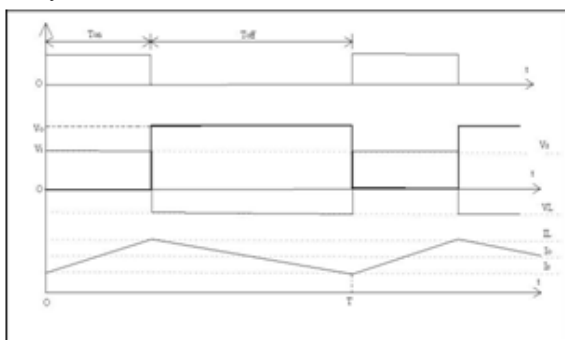


Figure 2. Waveforms of Current and Voltage in a Boost Converter Operating in Continuous mode.

During the On-state, the switch S is closed, which makes the input voltage (\$V_i\$) appear across the inductor, which causes a change in current (IL) flowing through the inductor during a time period (t) by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L} \tag{1}$$

At the end of the On-state, the increase of IL is therefore:

$$\Delta I_{L_{on}} = \frac{1}{L} \int_0^{DT} V_i dt = \frac{DT}{L} V_i \tag{2}$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is on. Therefore D ranges between 0 (S is never on) and 1 (S is always on).

During the Off-state, the switch S is open, so the inductor current flows through the load. If we consider zero voltage drop in the diode, and a capacitor large enough for its voltage to remain constant, the evolution of IL is:

$$V_i - V_o = L \frac{dI_L}{dt} \tag{3}$$

Therefore, the variation of IL during the Off-period is:

$$\Delta I_{L_{off}} = \int_0^{(1-D)T} \frac{(V_i - V_o)}{L} dt = \frac{(V_i - V_o)(1-D)T}{L} \tag{4}$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$E = \frac{1}{2} L I_L^2 \tag{5}$$

So, the inductor current has to be the same at the start and end of the commutation cycle. This means the overall change in the current (the sum of the changes) is zero:

$$\Delta I_{L_{on}} + \Delta I_{L_{off}} = 0 \tag{6}$$

Substituting $\Delta I_{L_{on}}$ and $\Delta I_{L_{off}}$ by their expressions yields:

$$\Delta I_{L_{on}} + \Delta I_{L_{off}} = \frac{V_i DT}{L} + \frac{(V_i - V_o)(1-D)T}{L} = 0 \tag{7}$$

This can be written as:

$$\frac{V_o}{V_i} = \frac{1}{1-D} \tag{8}$$

This in turns reveals the duty cycle to be:

$$D = 1 - \frac{V_i}{V_o} \tag{9}$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

B. Discontinuous mode of operation

The amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle as shown in Fig.3. Although slight, the difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value

$$I_{L_{Max}} \text{ (at } t = DT) \text{ is : } I_{L_{Max}} = \frac{V_i DT}{L} \tag{10}$$

During the off-period, IL falls to zero after δT :

$$I_{L_{Max}} + \frac{(V_i - V_o)\delta T}{L} = 0 \tag{11}$$

Using the two previous equations, δ is:

$$\delta = \frac{V_i D}{V_o - V_i} \quad (12)$$

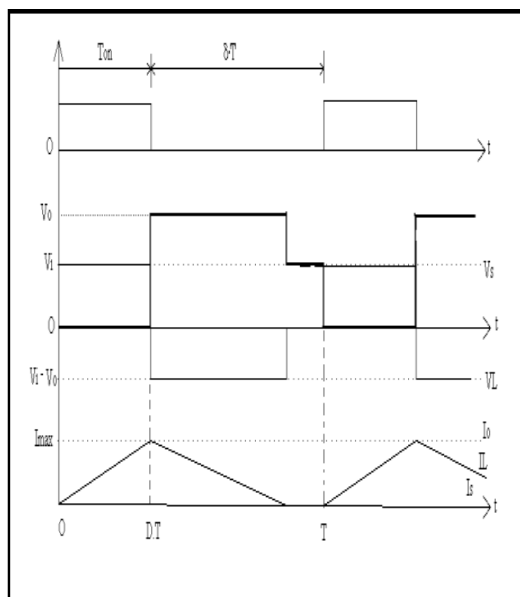


Figure 3. Boost Converter Current and Voltage Waveforms in Discontinuous mode

The load current I_o is equal to the average diode current (I_D). The diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$I_o = I_D = \frac{I_{Lmax} \delta}{2} \quad (13)$$

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2L I_o} \quad (14)$$

III. DESIGN CONSIDERATIONS

The main calculation in the system design includes the calculation of the snubber components along with the load parameters.

1. Resonant capacitor C_r

The resonant capacitor C_r is the sum of the parasitic capacitor of S_1 and the other parasitic capacitors incorporating it. The value of C_r is approximately 1nF.

2. Snubber inductor L_s

To turn ON auxiliary switch with ZCS, the required series inductor L_s is calculated

$$V_o - V_{cs1} * \frac{tr2}{L_s} \leq I_{i max}$$

$$L_s \geq (V_o - V_{cs1}) * \frac{tr2}{I_{i max}}$$

$$L_s \geq 1.4\mu$$

From the above designed parameters the proposed circuit is simulated in MATLAB Simulink software package and hence appropriate results are

obtained as shown below. The overall efficiency of 98% is obtained. The obtained values can be considered as

IV. SIMULATION RESULTS AND DISCUSSIONS

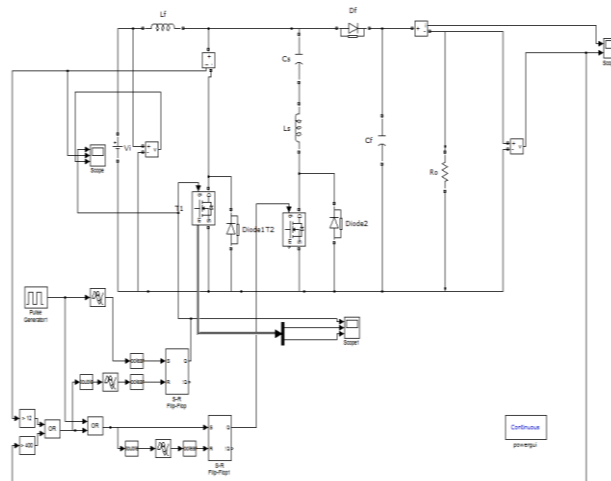


Figure. 6 Simulink Model for Proposed ZVT-ZCT Converter

The simulation model for PWM boost converter is given in Fig. 6. The circuit consists of a boost inductor, a MOSFET switch, boost diode and a output capacitor. The input current is assumed to be constant and input voltage is 200V DC. The pulse to gate of MOSFET switch is given from the pulse generator block. Scope displays the different waveforms of the PWM boost converter. The MOSFET switch operates at a frequency of 100 KHz. The pulse width selected was 50%. The load considered is of 160 Ω resistive load.

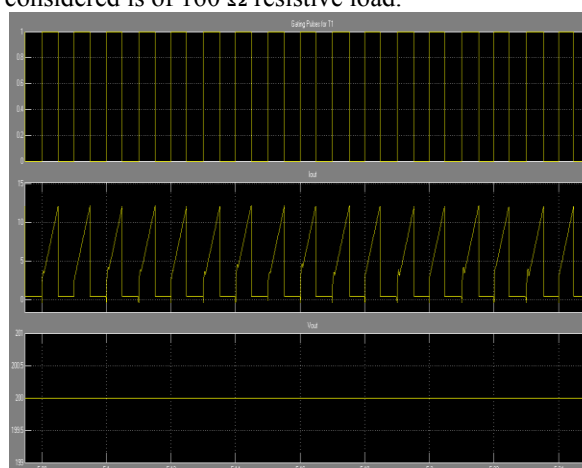


Figure.7 Input voltage and Current for corresponding pulses.

MOSFET along with its body diode is used as auxiliary switch in the proposed work. The voltage is a pulse wave that is obtained by soft switching of the converter.

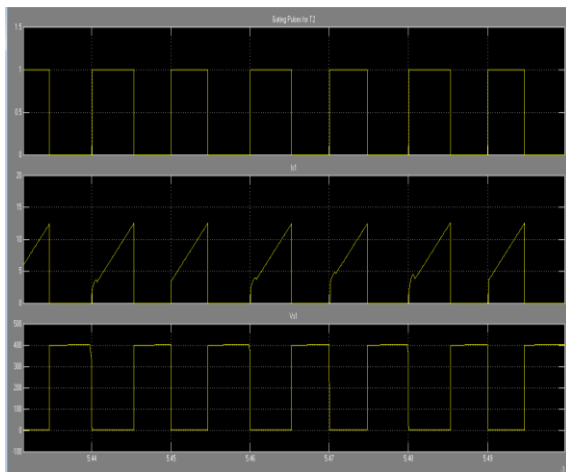


Figure. 8 Voltage and Current across the Main Switch illustrating ZCS and ZVS

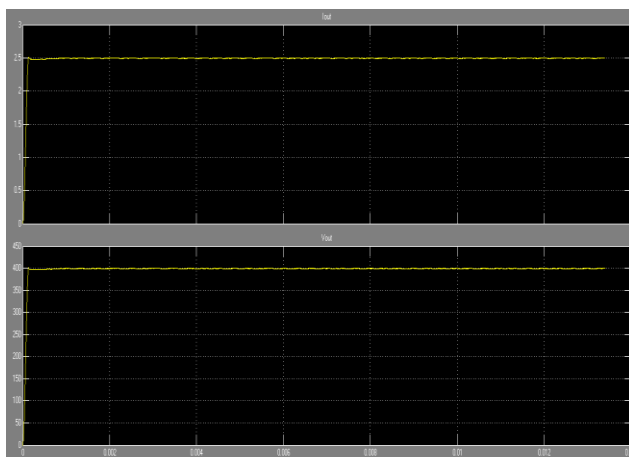


Figure. 9 Voltage and Current across the Load.

V. ADVANTAGES OF THE PROPOSED CONVERTER

Although there are some ZVT-ZCT DC-DC boost converters in literature, the proposed converter get full benefits of them. As a result, advanced soft switching techniques are used for the proposed converter not only for lowering the current stress on power switches but also improving the efficiency.

1. The main switch is turned on with ZVT and turned off with ZCT.
2. The auxiliary switch is turned on with ZCS and turned off with ZCT.
3. The main diode is turned on with ZVS and turned off with ZCS and ZVS.
4. The main switch extra voltage and current stress are disappeared.
5. Although soft switched active snubber cell is used in the proposed converter, total time interval is sufficiently small to work as normal PWM control.
6. The proposed active snubber cell can be used for higher power levels for many DC-DC PWM converters.

7. High switching frequency gives advantage of fast control and high power density with lowered component values.
8. The proposed active snubber cell can be used for higher power levels for many DC-DC PWM converters.

VI. CONCLUSION

The ZVT -ZCT Boost Converter provides a complete and perfect zero current and voltage operation of the power electronic switches. In ZVT-ZCT Boost Converter with the reduced output filter inductance, the converter has potentially high power density and rapid dynamic response. It is quite suitable in high power and high input voltage with wide range applications. The ZVT-ZCT Boost Converter can be used in energy harvesting applications such as solar, piezoelectric materials, thermocouple etc.

The new converter has a simple structure, low cost and ease of control. The effect of parasitic elements and reverse recovery losses in diodes are the major problem in this type of converters. In this type of converters the snubber circuit is made for the lowest input voltage and the highest load current. The diodes used in the proposed snubber circuits have low reverse recovery time period. This helps in eliminating stored charges in diodes during turn off. The snubber circuit does not have any coupled inductor or bulky transformers and thus magnetic losses are reduced. The proposed converter can be used for Electric vehicles, Portable Lighting systems, charger Circuits, in Desert Agriculture, in Air Conditioning Systems, PV power generation scheme without step-up transformer.

In this study, a PWM boost converter with a novel active snubber cell has been analysed in detail. This active snubber cell provides ZVT turn on and ZCT turn OFF together for the main switch of the converter. Also, the proposed snubber cell is implemented by using only one quasi-resonant circuit without an important increase in cost and complexity.

In the proposed converter, all semiconductor devices are switched under soft switching. In the ZVT and ZCT processes, the auxiliary switch is turned ON under ZCS and is turned OFF with ZCT and near ZCS, respectively. There is no additional voltage stress across the main and auxiliary switches. The main diode is not subjected to any additional voltage and current stresses. The operation principles and steady-state analysis of the proposed converter are presented. It is observed that the operation principles and the theoretical analysis of the novel converter are exactly verified by experimental results taken from the converter operating at 1 kW and 100 kHz. Additionally, at nominal output power, the converter efficiency reaches approximately to 97.8%.

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