ZVS Boost Converter with A Flyback Snubber Circuit

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Abstract—Power semiconductors are the heart of power electronics equipment. Snubbers are circuits which are placed across semiconductor devices for protection and to improve performance.In this paper, several passive and active snubbers associated with boost converters are first reviewed, and their limitations are then addressed. One of the boost converters with a flyback snubber is proposed.The proposed converter configuration can achieve both near zero-voltage and zero-current soft-switching features, while it can reduce the current and voltage stresses of the main switch. Experimental results obtained from a 5W boost converter have confirmed that the proposed converter configuration is attractive and feasible for high power applications.
Index Terms—Active snubber, boost converter, current stress, flyback snubber, passive snubber.

I. Introduction

RENEWABLE energy resources have drawn a lot of attention. Photovoltaic (PV) energy is most popular as it is clean, maintenance free, and abundant. In order to obtain maximum power from PV modules, tracking the maximum power point of PV arrays is usually an essential part of a PV system, which is mostly realized with a boost converter.

For high power applications, component stress, switching loss, and electromagnetic interference noise are increased due to high di/dt of diode reverse-recovery current and high dv/dt of MOSFET drain source voltage, resulting in low reliability and even violation of regulation. Hence, passive and active snubbers were introduced to the boost converter.

Snubbers can do many things:
1) Reduce or eliminate voltage or current spikes
2) Limit dI/dt or dV/dt
3) Shape the load line to keep it within the safe operating area (SOA)
4) Transfer power dissipation from the switch to a resistor or a useful load
5) Reduce total losses due to switching
6) Reduce EMI by damping voltage and current ringing

II. REVIEW OF THE BOOST CONVERTER WITH SNUBBERS

Snubbers can either be passive or active networks. The basic function of a snubber is to absorb the energy from the parasitic devices in the power circuit to achieve soft switching features. The extra snubber or commutation cell can create a short time interval of zero-voltage transition or zero current transition for the main switch to achieve a zero voltage switching (ZVS) turn- ON or a zero-current switching (ZCS) turn-OFF process [1]-[3]. However, high voltage or high current stress still appears on the main switch. In the following, the main-switch soft-switching features with its voltage and current stresses will be discussed according to the snubber types of passive and active.

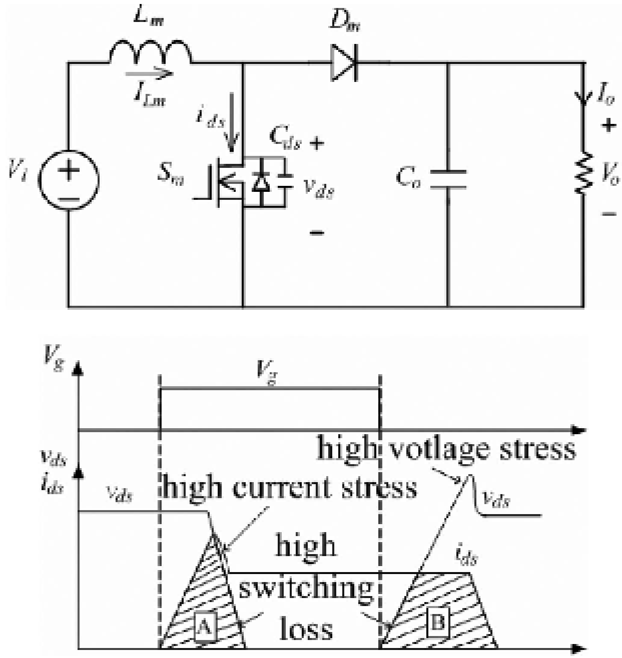


FIG. 1. CONVENTIONAL BOOST CONVERTER.

Fig. 1 shows a conventional boost converter and its conceptual switch gate signal, and voltage and current waveforms. It can be observed that when the main switch is turned on, high current stress will occur, which is primarily due to the reverse recovery current of diode Dm and input inductor current I□m. On the other hand, when the switch is turned off, high voltage stress will impose on the main switch caused by input voltage Vi, finite forward recovery time of Dm, and the ringing between parasitic devices. These will result in turn-ON and turn-OFF switching losses, as shown in areas A and B, respectively, and deterioration in conversion efficiency and reliability.

III. WITH PASSIVE SNUBBERS

Passive snubbers are widely used in boost converter applications because they do not require many components and complex control, which can achieve soft-switching features [4]-[13].

To achieve near ZVS turn-ON soft-switching feature, an inductor is usually placed in series with the main switch or the diode to slow down diode reverse-recovery current.To achieve a turn-ON soft-switching feature, inserting an inductor in series with the main switch or diode is consequently adopted, as shown in Fig. 2. Inductor Ls can limit reverse recovery current from diode Dm and share input inductor current flowing through main switch Sm during switching transition, achieving a near ZVS feature. Although turn-ON loss can be improved, part of inductor current will charge capacitor Cds before I□s= I□m , resulting in high voltage stress imposed on the main switch.

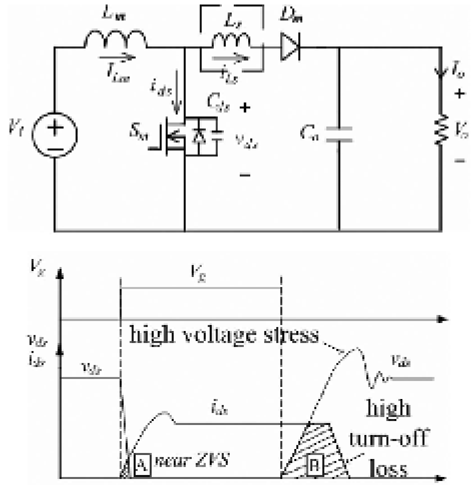


Fig. 2. Boost converter with a snubber inductor Ls

In these snubbers, although the inductor can alleviate reverse-recovery current, it induces extra voltage stress on the main switch at turn-OFF transition and would increase switching loss. Thus, a snubber capacitor is required to absorb the energy stored in the snubber inductor and to clamp the switch voltage. However, for saving component count, the energy stored in the snubber capacitor is recycled through the main switch, resulting in high current stress. It would deteriorate converter reliability and life span.

For resolving the aforementioned problem, snubber capacitor Cs is added between components Ls and Dm, and two diodes D1 and D2 are used to clamp Vds [4]-[6], as shown in Fig. 3. Note that Ls can be relocated to be in series with switch Sm. The reverse-recovery current in Ls creates the first resonant path of Ls-D1-Cs to charge Cs through D1 . Even though the energy stored in Cs can help raise I□s, the main switch still turns off with hard-switching manner. Moreover, after Cs has been completely discharged, a large portion of current I□m will flow though diodes D1 and D2 , increasing conduction loss a lot. Thus, efficiency and reliability of the converter have not been optimally improved yet.

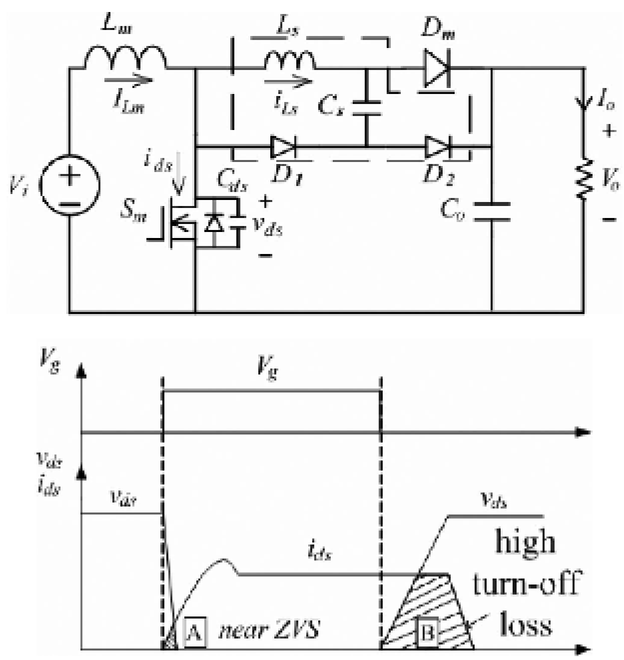


Fig. 3. Boost converter with a low voltage stress turn-ON snubber.

Due to less degrees of freedom, a boost converter with passive snubbers has the difficulty to achieve both near ZVS and ZCS, and also to keep low voltage and current spikes or stresses for the main switch.Thus, active snubbers were introduced to the boost converter.

IV. With Active Snubbers

Nowadays, there has been a lot of study about various types of active snubbers to reduce either switching loss or voltage and current stress.

Among the proposed active clamp snubbers, the buck active clamp is first adopted with the boost converter, as shown in Fig. 4. It can clamp the switch voltage while inductor current I□s tracking inductor current I□m at the main switch turn-off transition. However, clamping capacitor voltage Vcs cannot be drained out during the main switch turn-on state, resulting in significant turn-off loss. Thus, a boost converter with a boost active clamp snubber, as shown in Fig. 4(b), is introduced to relieve the above drawback.With a boost active clamp snubber,to the energy stored in Cs can be effectively transferred to the output in every switching cycle and a ZVT feature can be attained at the main switch turn-off transition. Although the circuit has the merit of a ZVT feature, it still suffers from high voltage spike imposed on the main switch Sm at the switch turn-off transition.

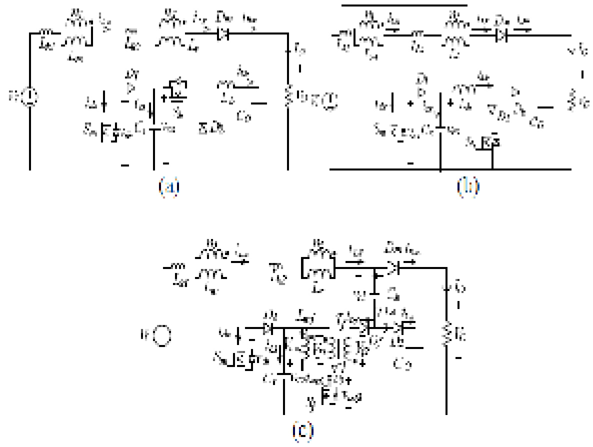


Fig. 4. Boost converter with a (a) buck (b) boost and
(c) flyback active clamp circuit.

To solve the above mentioned problem, a boost converter with a flyback active clamp snubber, as shown in Fig. 4(c), is therefore proposed. It can relieve the drawbacks of high current and high voltage stresses imposed on the main switch at turn-on and off transitions. The active snubber only deals with around 1% of the full load power, and it is operated in DCM to avoid high voltage or current spike.

V. PROPOSED CONVERTER CONFIGURATION

Designing a snubber with high performance needs to consider various indexes of switching loss, current and voltage stresses, snubber circulation loss, duty loss, duty range, control complexity, component count, and processed power. In fact, there is no single passive or active snubber, which can meet all of the aforementioned performance considerations.This paper presents a boost converter with a low power-rating flyback active snubber for high input current/high power applications while achieving near ZVS and ZCS soft-switching features.The proposed boost converter, as shown in Fig. 5, is formed with a main switch Sm, coupled inductors Lm and Ls and a flyback snubber. In the circuit, Lk1 and Lk2 are the leakage inductance of coupled inductor Tx.

In Fig. 5, clamp-branch diode D1 and capacitor Cs can help achieve near ZCS for Sm. The energy stored in capacitor Cs does not circulate through main switch Sm while it is transferred to Cb through the flyback snubber, which is operated in discontinuous conduction mode (DCM) to reduce switching loss and voltage stress.The capacitor Cb not only buffers the energy transferred from Cs,but reduce voltage stress on Sm at turn-OFF transition.

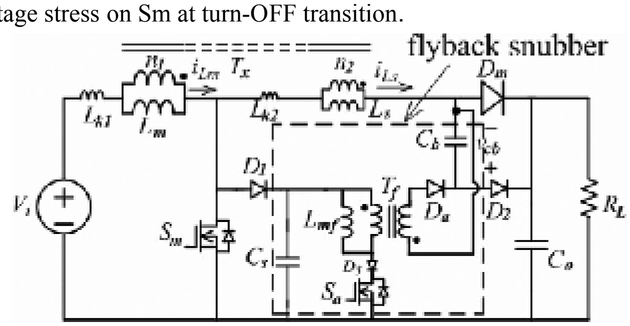


Fig. 5. Proposed boost converter with a flyback active snubber.

The key current and voltage waveforms of the converter are shown in Fig. 6. Note that the proposed flyback snubber can be integrated with other pulse width modulation (PWM) converters, such as buck, buck-boost, and Cuk, to achieve the

Same soft-switching features.

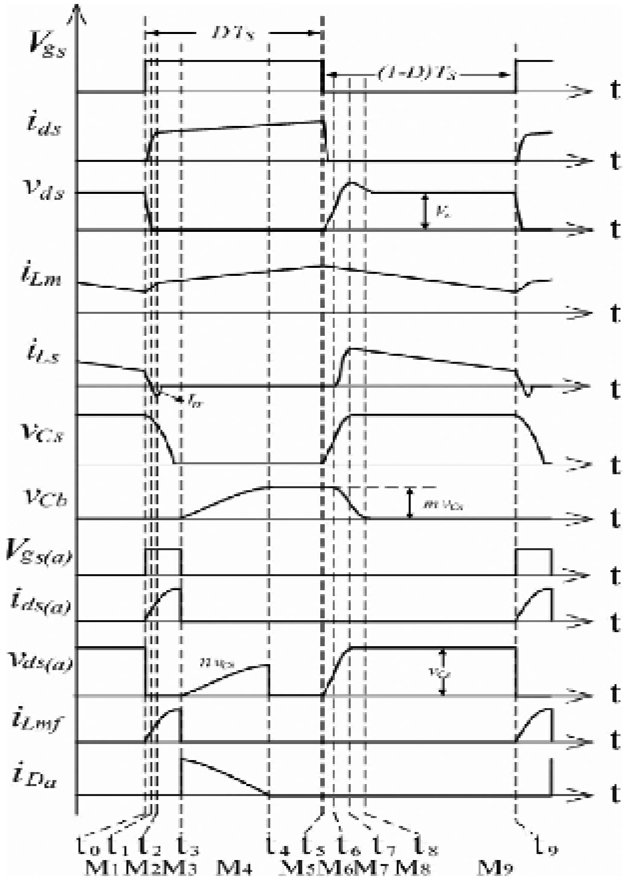
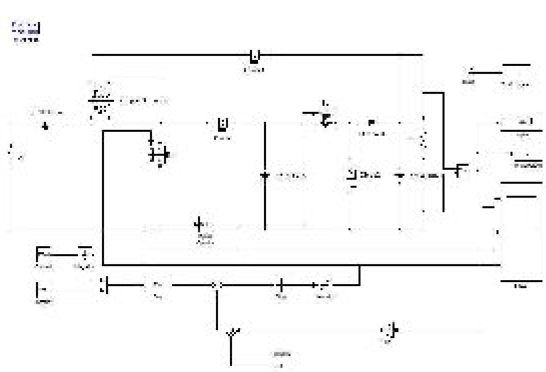
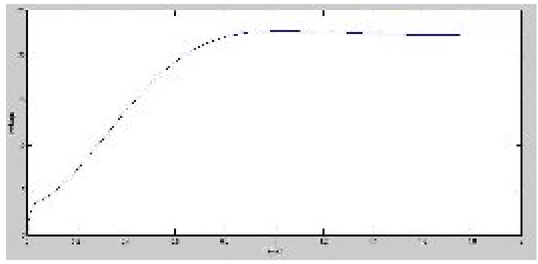


Fig. 6. Key current and voltage waveforms of the proposed converter.

VI SIMULATIONS

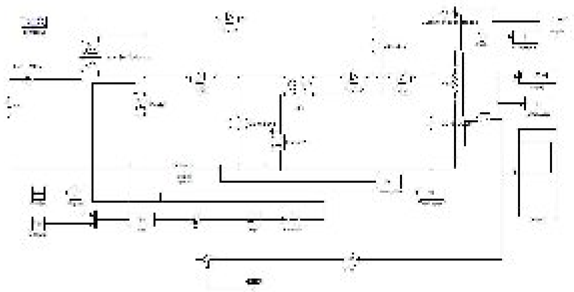
Boost converter with Buck active clamp circuit

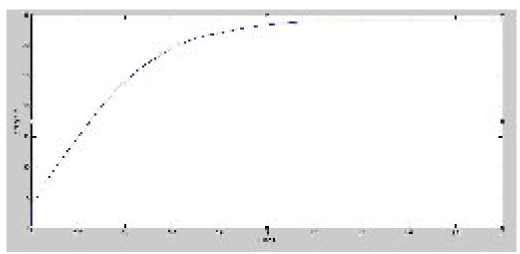




Output voltage waveform

Boost converter with Flyback Snubber circuit





Output voltage waveform

VII HARDWARE DESIGN

A. DESIGN OF THE BOOST CONVERTER

1. MAIN SWITCH (Sm)

To operate the converter at a 5W power rating and 20-kHz switching frequency, the main switch can be MOSFET. Generally, IGBT devices are suitable for the main switch when the converter is designed for high power applications. Considering the effects of tail current, latch up, and negative temperature coefficient (most commercially available), the proposed converter does not use IGBT as the main switch, whereas a parallel connection of MOSFETs is adopted. In the experiment, two MOSFET IRF830 with Rds (on) = 1Ω,500V,4A were selected. In fact, it can be operated at higher switching frequency, but a time interval for the flyback snubber to transfer the energy from capacitors C*s* to C*b* has to be sustained.

2. MAIN INDUCTOR (Lm)

The main inductance of 1.5mH was designed based on (1), which can be operated at continuous conduction mode

$$L_m > L_B = (V_o T_s / 2 I_o B)\, D\, (1-D)^2 \quad\ldots\ldots\ldots (1)$$

Where LB is the boundary inductance, Ts is the switching period*, IoB* is the boundary output current, and D is the duty ratio. For main inductor toroidal core is used. L*s* is designed to be 0.1mH. The winding18-AWG copper wires with 10 turns for L*m* and 3 turns for L*s* were designed.

3. MAIN DIODE (Dm)

The main diode contributes most of the loss in the converter. In considering fast reverse recovery, low forward voltage drop, and sufficient voltage rating, the boost diode (D4L2U)

4. OUTPUT CAPACITOR (Co)

The output capacitor is used to buffer output voltage, suppress spikes, and filter ripple. It also needs to consider the entire load current under the full-load condition and system dynamic performance. Hence, 470 μf electrolytic capacitor was adopted for output capacitor Co.

B. DESIGN OF THE FLYBACK SNUBBER

A flyback snubber is to transfer energy from snubber capacitor C*s* to buffer capacitor C*b* , which can attain near ZCS turn-off and ZVS turn-on for main switch S*m*. The key components of D1 , D2 , L*s* , C*s* , C*b* , L*mf* , S*a* , D3 , and D*a* are designed as follows.

1.FLYBACK SNUBBER

The design steps for flyback is given in appendice. E core is used with turns ratio 1:2.Primary having 0.1mH (30 turns) and secondary 0.2mH (60 turns).

2. CLAMPING DIODE (D1) AND DIODE (D2)

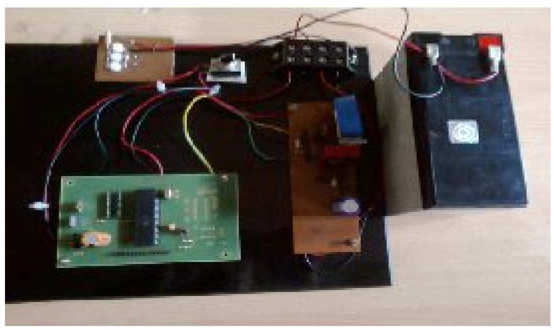
Diodes D1 and D2 are placed at input and output of the flyback snubber. The task of D1 is to block the current from C*s* flowing through the main switch, and D2 is to block output current Io flowing to the flyback snubber. The voltage and current ratings of diode D2 must be greater than output voltage Vo , and its average rectifier current should be greater than snubber inductor current IL*s*.

3.SNUBBER CAPACITOR (C*s*) AND SNUBBER INDUCTOR (L*s*)

Snubber capacitor Cs is to absorb current difference between currents I*Lm* and I*Ls*, which can attain near ZCS soft-switching feature for the main switch. Current I*Lm* will flow through the path of Lk2-Ls-Cb-D2-Co with a resonant manner, which creates a near ZCS operational opportunity for main switch S*m*.

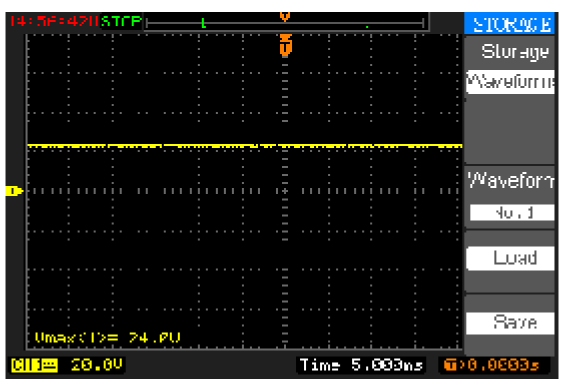
VIII. HARDWARE PROTOTYPE

To verify the proposed converter performance, an experimental prototype of 5W boost converter with a flyback snubber was designed and built



Hardware Assembly

A 12 V Battery is used as DC source. If AC supply has to be given as input, then provision is done in hardware ie, supply can be given to the bridge rectifier circuit (using diodes IN4007). Power conditioning circuit essentially supplies the power requirements for varies elements in the hardware such as MOSFET switches, PIC etc, at the rated voltage levels. The voltage regulator LM317 is used .The output is 5V which can be given to the microcontroller



Output voltage

IX.CONCLUSION

In this paper, several passive and active snubbers associated with boost converter are reviewed, and addressed their limitations.The proposed boost converter with flyback snubber can achieve the highest efficiency, while sustain low current and low voltage stresses. Although the proposed flyback active snubber does not need high switch current rating, it requires more component count. As a part of future work, feedback circuit can be added so that the output voltage can be held constant. The proposed flyback snubber can be integrated with other PWM converters to achieve soft-switching feature and low component stress.

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