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Soft Switching Boost Converter with a Fly back Snubber For Higher Power Applications

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ABSTRACT: This paper presents dc-dc converter operation of boost converter are an enabling soft switching technology. This proposed converter configuration can achieve zero voltage switching. The circuit consists of a general boost Converter with an auxiliary circuit which has a additional switch, and resonant components (snubbers). Boost converter has loss mechanism, current stress and voltage stress. by using this auxiliary switch and resonant components not only achieving soft switching feature and also reduce switching loss current and voltage stress, reduce harmonics and ripples in the input current and output voltage. Main and auxiliary switch achieving ZVS and ZCS simultaneously reduce losses. This leads to improving the efficiency of DC-DC conversion. This theoretical analysis, operational principle, design method is presented. MATLAB simulations are performed to verify the theoretical analysis.
Index Terms- Active Snubber, boost converter, soft switching, zero voltage switching.

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. Boost converter is one of the most important and widely used devices of modern power applications. Till now Boost Converters with snubber circuits are used where switching losses are dissipated in external resistors leading to higher switching losses and low overall efficiency.

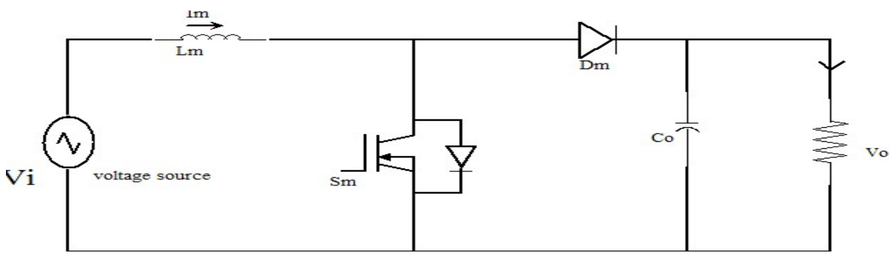

Fig.1: Normal boost converter

Vi=INPUT SOURCE
Dm=MAINDIODE; Co=OUTPUT CAPACITOR
Vo=OUTPUT VOLTAGE

II. NORMAL BOOST CONVERTER

Modern Boost converters use MOSFET switch which is operated in low frequency range. Increasing frequency of converter operation is desirable circuit size and capacitor rating is reduced, cheaper and circuit is simple. But this leads to increasing switching loss and reduce system efficiency. Switch is operated in 20 KHz frequency range. To achieve near ZVS turn-on soft-switching feature, inductor is usually placed in series with the main switch or the diode to slow down diode reverse-recovery current.

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. To release the aforementioned high current stress, active snubbers are applied to the boost converter.

They can not only attain soft-switching features, but significantly reduce voltage and current stresses. However, in the active snubber, its auxiliary switch needs to sustain at least the same current rating as that of the main switch because the input inductor current flows through the auxiliary switch during the main switch turn-off transition, reducing efficiency and reliability. In the boost converter with a low voltage stress turn-on snubber is integrated with an active snubber. It can improve high turn-off loss and achieve near ZCS turn-off and ZVS turn-on soft-switching features for the main switch. However, its input and resonant currents will flow through the active snubber, resulting in high current stress on the auxiliary switch. Hence, to reduce the current rating of the auxiliary switch, a low power-rating fly back active snubber is introduced to the boost converter with a passive snubber.

Additionally, it still can achieve near ZVS and near ZCS, and reduce current and voltage stresses imposed on the main switch.

III. PROPOSED BOOST CONVERTER

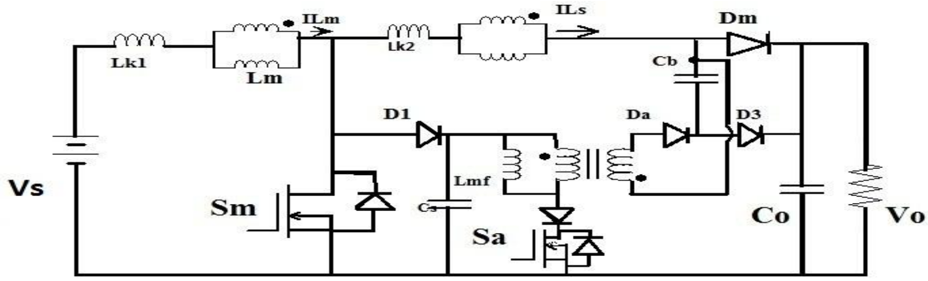

Fig.2: boost converter with snubber and ZVS

This proposed boost converter configuration have soft switching can be obtained by using PWM signal generator, PWM signal controllers, MOSFET switches and snubbers reducing switching losses and harmonics to increase the efficiency. IC LF137 is used for generating of PWM signals. LF 137 has some operational amplifiers (IC CA3140).it is used produce square pulses and triangular pulses. These pulses are compared with a reference signal in comparator to produce the PWM digital pulses these digital pulses are fed to driver circuit.

IR 2110 this IC is used for driving PWM signals. Driver circuit drive PWM signals into desired frequency range. In this circuit 25 kHz frequency is needed to switching the MOSFET. Two MOSFET switches are switched at desired time interval. Soft switching is implemented above.

ZVS is achieved for turn on the MOSFET. Capacitor is added parallel across the MOSFET to achieve ZVS turn on.When zero voltage is reached MOSFET is turned on this voltage level. At zero current level is reached parallel of MOSFET diode MOSFET is turn-off. The auxiliary switch is reached ZVS turn on. Snubber capacitance and inductance is used to protect main and auxiliary MOSFET from reverse current and voltage stress. Fly back numbers are mainly used to protect switches from reverse recovery current and voltage stress and these snubbers

IV. DESIGN PROCEDURE AND PRACTICAL CONSIDERATION

This section presents the design of the power converter and selection of the major components. A brief design procedure is described as follows

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4.1 DESIGN OF THE BOOST CONVERTER:

4.1.1Main Switch (Sm): To operate the converter at a 5-kW power rating and 25-kHz switching frequency, the main switch can choose insulated gate bipolar transistor (IGBT), MOSFET, Cool MOS, or even better performance devices. 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 MOSFET is adopted. In the experiment, two MOSFETIXFH36N50P with Rds(on) = 0.0001 Ω were selected. In fact, it can be operated at higher switching frequency, but a time interval for the fly back snubber to transfer the energy from capacitors Cs to Cb has to be sustained.

4.1.2 Main Inductor (Lm): The main inductance of 1.2mH was designed based on, which can be operated at continuous conduction mode.

$$Lm > LB = VoTs/2IoBD\ (1 - D)^2$$

Where LB is the boundary inductance, Ts is the switching period, IoB is the boundary output current, and D is the duty ratio. In addition, core loss, saturation flux density, and frequency response of the inductor are also needed to be considered. Hence, according to the data sheet, two toroidal cores CH571125 in parallel are selected for the main inductor. The winding of two paralleled 18-AWG copper wires with 43 turns was designed.

4.1.3 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 is chosen with the rating of 600 V/60 A, DSEI 60-06A.

4.1.4 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, three 2000- mF electrolytic capacitors in parallel are adopted for output Capacitor Co.

Table 1: Capacitance (co) versus voltage (Vco)

CAPACITANCE Co(mF)	VOLTAGE Vco(V)
200	582(linearly step down)
500	496(linearly step down)
2000	196(constant)

4.2 DESIGN OF THE FLYBACK SNUBBER: A fly back snubber is to transfer energy from snubber capacitor Cs to buffer capacitor Cb, which can attain near ZCS turn-off and ZVS turn-on for main switch Sm. The key components of D1 , D2 , Ls , Cs , Cb , Lmf , Sa , D3 , and Da are designed as follows

4.2.1 Clamping Diode (D1) and Diode (d2): Diodes D1 and D2 are placed at input and output of the fly back snubber. The task of D1 is to block the current from Cs flowing through the main switch, and D2 is to block output current Io flowing to the fly back snubber.

The 600-V/30-A rating of HFA30PA60C ultrafast soft recovery diode can be used for D1. 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 iLs. Thus, diode D2 can be chosen with the rating of 600 V/30 A HFA30PA60C.

4.2.2 Snubber Capacitor (Cs): Snubber capacitor Cs is to absorb current difference between iLm and iLs, which can attain near ZCS soft-switching feature for the main switch. Considering the processed power being around 1% of the full load power and based on the relationship between capacitance Cs and voltage VCs is shown in Table I. In practice, the capacitance of Cs is chosen as 100mF.

4.2.3 ***Snubber Inductor and Capacitor set (Ls, Cs, and Cb):*** Design of snubber inductor Ls and capacitor setCs andCb can be achieved with MATLAB software package. Current iLm flows through the low impedance-path capacitor Cs. Relationship among VCs, Vo, and VCb can be expressed as follows:

$$VCs < Vo – VCb(t6)$$
$$iLs = 0;$$
$$iCs = iLm ;$$
$$Cs\ dvCs/dt = iCs$$

WhereVCb (t6)is the initial value of vCb. When capacitor Cs is charged to be high enough, it means that equation (9) is satisfied, and the converter enters M7 operation. Current iLm will flow through the path ofLk 2–Ls–Cb–D2–Co with a resonant manner, which creates a near ZCS operational opportunity for main switch Sm. The following relationship can be obtained:

$$\text{When } vCs \geq Vo – VCb(t6)$$

$$C_s\, dv_{Cs}/dt = i_{Cs}$$
$$L_s\, di_{Ls}/dt = v_{Cs} - (V_o - v_{Cb})$$
$$C_b\, dv_{Cb}/dt = i_{Cb} \quad i_{Cs} = i_{Lm} - i_{Ls}.$$

Based on the aforementioned conditions, snubber inductance Ls, processed power of the fly back snubber, capacitor set Cs and Cb, and voltage vCs and vCb can be derived. It can be proved that higher snubber inductance Ls can reduce diode reverse-recovery loss, whereas the fly back snubber needs to process higher power and higher voltage will cross the snubber capacitor, resulting in lower conversion efficiency. In considering voltage stress on switch Sm, circulation loss, turn-off loss, and design margin, a proper capacitor set of Cs = 100mF and Cb = 2000mF is chosen for the proposed converter. Coupled inductor Ls and its leakage inductance are used to limit the reverse-recovery current of diode Dm. It is chosen as Ls = 2mH to limit the current effectively.

V. MODE OF OPERARTION:

Mode 1 [t0 ≤ t < t1]:

Before t0, main switch Sm was in the OFF state. The driving signals of both boost converter and fly back snubber are synchronously started at t0. Continue In this mode, the boost converter achieves a near ZVS soft switching feature, and current iLs drops to zero gradually. In the fly back snubber, the energy stored in capacitor Cs will be delivered to magnetizing inductance Lmf, current iLmf is therefore built up, and the equivalent circuit is shown in during the energy-transfer process, both components Cs and Lmf are in resonance. Currents iCs(t), iLmf(t), and ids(f)(t) are identical; thus, current iCs (t) and voltage vCs (t) can be derived as follows:

$$i_{Cs}(t) = v_{Cs}(t_0)/Z_0 \sin\omega_0 (t - t_0) \quad (1)$$

And

$$v_{Cs}(t) = v_{Cs}(t_0) \cos\omega_0 (t - t_0) \quad (2)$$

Where the resonant frequency ω0 and the characteristic impedance Z0 are, respectively, expressed as follows:

$$\omega_0 = 1/L_{mf}C_s \quad (3)$$

$$\text{And } Z_0 = L_{mf}/C_s \quad (4)$$

Since the flyback snubber is operated in DCM, the current and voltage rating of switch Saare primarily determined by iCs and vCs. Moreover, since capacitor Cs can absorb the current difference between iLm and iLs, switch Sa does not need a current rating as high as that of Sm.

Mode 2[t1 ≤ t < t2]:

Afterward, boost diode Dm is in reverse bias, The di/dt of the boost diode reverse-recovery current is primarily limited by leakage inductance Lk2.

Mode 3 [t2 ≤ t < t3]:

In this mode, boost converter and fly back snubber are also maintained in the ON state.
The energy from capacitor Cs is still delivered to magnetizing inductance Lmf.

Mode 4[t3 ≤ t < t4]:

When switch Sa is turned off at t3 , the energy stored in inductance Lmf starts to transfer to buffer capacitor Cb by way of Da, During this interval, both magnetizing inductance Lmf and buffer capacitor Cb are in resonant manner;
as a result, current iCb (t) and voltage vCb (t) can be derived as
Follows:

$$\text{cb}\, icb(t) = ILmf(t3)\cos w3(t - t3) \quad (5)$$

And

$$v_{Cb}(t) = Z_3 I_{Lmf}(t_3) \sin\omega_3 (t - t_3) - V_{Lmf} \cos \omega_3 (t - t_3) \quad (6)$$

WhereILmf (t3) is the initial current of magnetizing inductanceLmf at t3, and resonant frequency ω3 and characteristic
ImpedanceZ3 can be determined as follows:

$$\omega_3 = 1/L_{mf}C_b \quad (7)$$

And

$$Z_3 = L_{mf}C_b. \quad (8)$$

Again, since the flyback snubber is operated in DCM, current iCb and voltage vCb will exclusively determine the ratings forDiode Da.

Mode 5[t4 ≤ t ≤ t5]:

Because the energy stored in magnetizing inductance Lmf was completely transferred to capacitor Cb at t4 , currents ids(a) , iLmf, and iDa, and voltage vds(a) are equal to zero in this interval. Voltage vCb is clamped till time t6

Mode 6[t5 ≤ t < t6]:

This mode begins when the main switch Sm is turned off, and the snubber capacitor Cs is charged until its voltage is satisfied with the relationship shown in the following:

$$VCs(t6) + VCb(t6) = Vo \qquad (9)$$

In this mode, the fly back snubber still stays in the OFF state.

Mode 7[t6 ≤t<t7]:

When (9) is satisfied, current iLs will start to track current iLm with a resonant manner, and capacitor Cb will start to release its stored energy. At time t7,current iLs is equal to current iLm. Meanwhile, the voltage of the main switch Sm and capacitor Cs will reach the maximum value simultaneously.

A near ZCS feature is therefore attained during t5–t7. In this mode, snubber capacitor Cs, equivalent inductance
(LX= Lk 2+ Ls), and buffer capacitor Cb are in resonance. Currents iLs(t) and iCs (t), and voltages vLs (t), vCb (t), and vCs (t) can be derived as follows:

$$iLs(t) = CXCs$$
$$ILm[1 - \cos \omega 6 (t - t6)] \qquad (10)$$
$$iCs(t) = ILm - CXCs$$
$$ILm[1 - \cos \omega 6 (t - t6)] \qquad (11)$$
$$vLs(t) = Z6ILmCXCs\sqrt{} \sin \omega 6 (t - t6) \qquad (12)$$
$$vCb(t) = ILmCs + Cb/\omega 6\sqrt{} \sin w6 (t - t6) - (t - t6+ VCb (t6) \qquad (13)$$

And

$$vCs(t) =1Cs\sqrt{}ILm(t - t6) \times (1 - CX Cs)+ CX ILmCs\omega 6$$
$$\sin\omega 6 (t - t6)+ VCs(t6) \qquad (14)$$

Where VCb (t6) and VCs (t6) are the initial value of capacitors Cb and Cs at (t6), respectively, ILm is a constant value, and capacitor CX , resonant frequency ω6 , and characteristic impedance Z6are, Respectively, expressed as follows:

$$CX = CsCbsCs + Cb \qquad (15)$$
$$\omega 6 =1 \sqrt{}LX CX \qquad (16)$$
$$Z6 = \sqrt{}LXCX \qquad (17)$$
$$LX = Ls + Lk2. \qquad (18)$$

Mode 8 [t7 ≤ t < t8]:

Before t8, the energy stored in buffer capacitor Cb was not completely drained out yet; thus, the capacitor will not stop discharging until its voltage drops to Zero. The energy stored in capacitor Cs is

$$WCs =12Cs \cdot v2Cs (t7) \qquad (19)$$

Based on the energy stored in capacitor Cs , we can determine the power rating Pf of the fly back snubber as follows:

$$Pf = WCs \cdot fs \qquad (20)$$

Under the conditions of Vi= 12V and Pmax = 5 kW, voltage vCs can be determined from (14) as around 196V; thus, the maximum power rating Pf (max) of the fly back snubber is just about 40W. The processed power by the fly back snubber is less than 1% of the full power rating (5 kW).

Mode 9[t8 ≤t<t9]:

When the energy stored in Cb has been completely released to the output at t8, diode Dm will conduct. In this interval, the voltage across the main switch will drop back to around output voltage Vo, and moreover, the circuit operation in this mode is identical to that of a conventional boost converter in the OFF state.

VI. EXPERIMENTALRESULTS

COMPONETS USED:

Mosfet switch (2)=IRF3460
Diode=DIN14007

Inductance (4)=2mH
Inductance=2pH
Inductance=2µH
Capacitance snubber=100mF
Capacitance buffer=2000mF
Capacitance output=2000mf

6.1 SIMULATION AND RESULT:

Simulation of this proposed boost converter is shown in below and its input voltage and current& output voltage and current wave forms and given below.

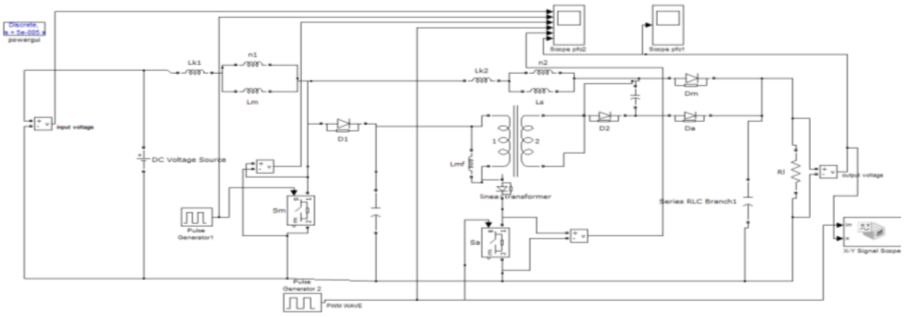

Fig3: Boost Converter Simulation Diagram

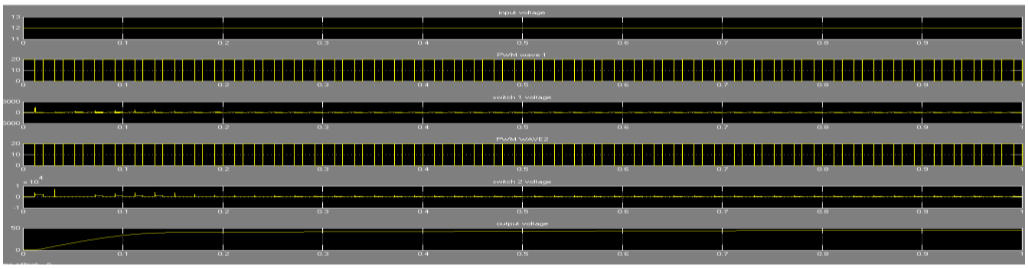

Fig4: Comparison of Pwm Pulses and Switch Voltage and Output Voltage

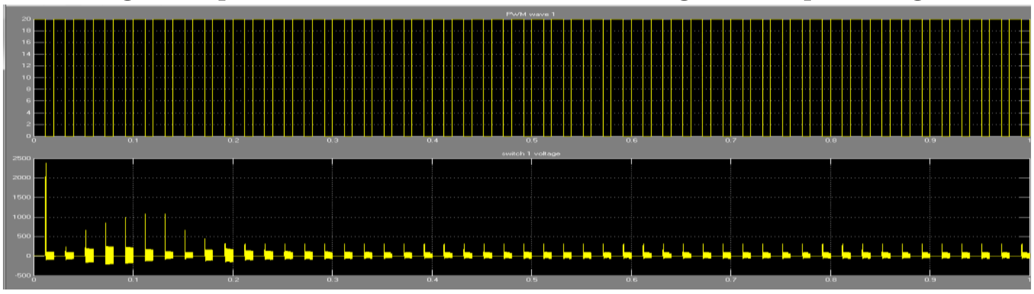

Fig5:Mosfet1 (Sm) voltage

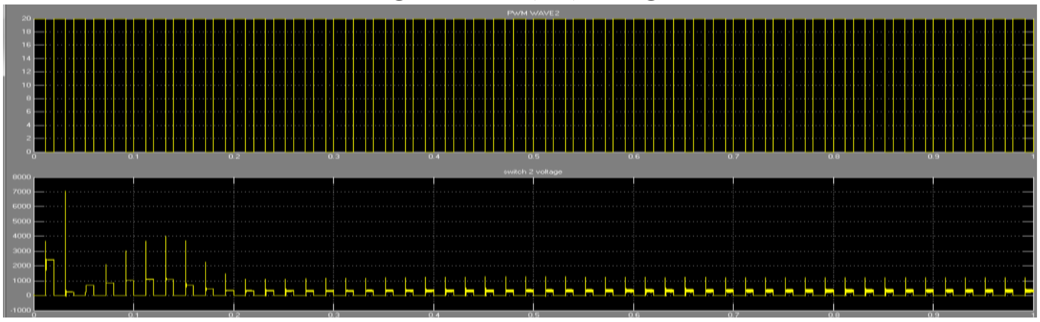

Fig6:Mosfet 2 (Sa) voltage

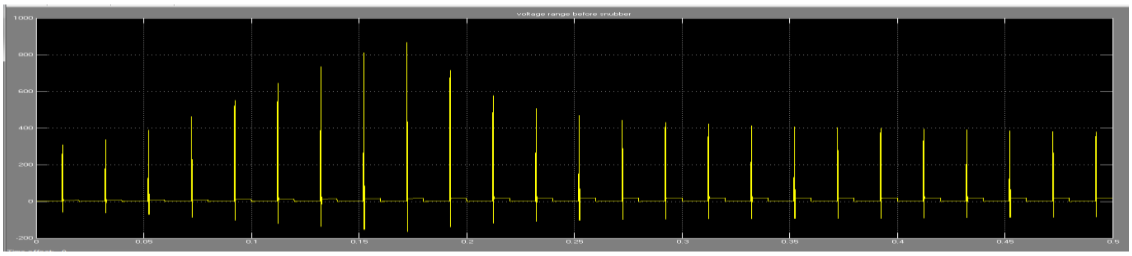

Fig7: Voltage Range Before Snubbers

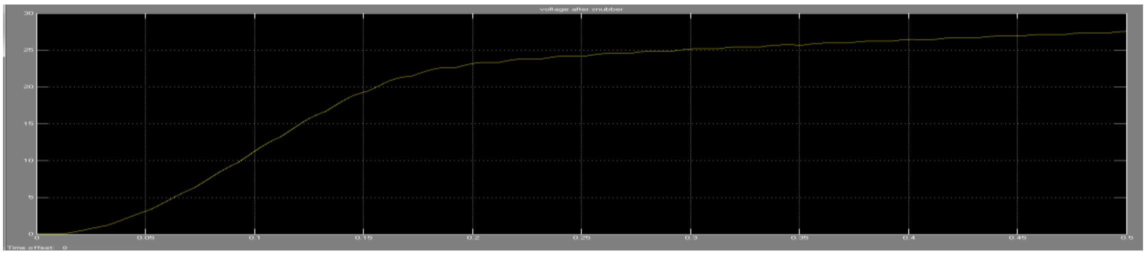

Fig 8: Voltage After Snubbers

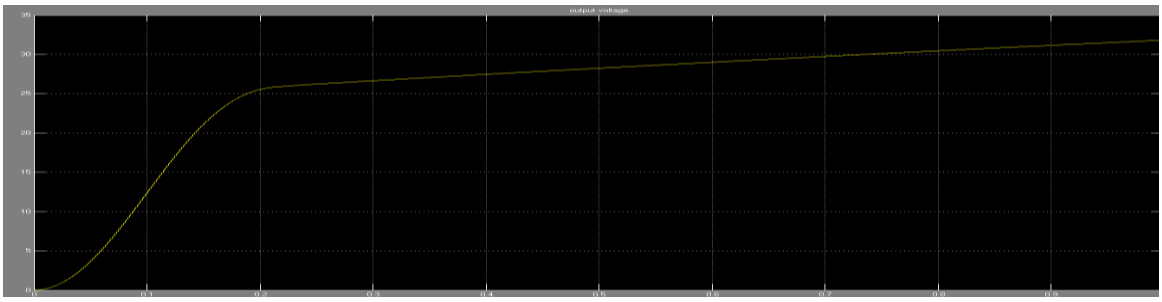

Fig 9: Output Voltage

VII. CONCLUSION

In this paper, a boost converter with a fly back snubber has been implemented to verify its feasibility. Theoretical analysis and design procedure have been presented in detail, and the performance of boost converters with active snubbers have been compared according to various indexes. Experimental results have shown that low current stress and near ZVS feature at main switch turn-on transition have been attained, and low voltage stress and ZVS turn-off transition have been also achieved. As compared with the conventional boost converter, the proposed converter can achieve the highest efficiency, while sustain low current and low voltage stresses. The maximum efficiency point can be shifted to a higher power level introducing larger core and lower copper wire gauge, which can reduce conduction loss. A boost converter with the proposed fly back snubber is relatively suitable for high power applications. Moreover, the proposed fly back snubber can be integrated with other PWM converters to achieve soft-switching feature and low component stress.

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