Development of Improved Power Conversion Efficiency of Closed Loop Boost Converter Using Snubber Circuit for LED Lighting System

Ainee Ansaari[1], **Jaidam Ram Tej**[2]

***Abstract*—This paper aims to present an effective approach to design a boost converter by improving the power conversion efficiency using a snubber circuit. The proposed system is then implemented to light up a 4X4 LED Panel.Passive snubber circuit is used to reduce switching losses. It has a number of advantages over the circuit without snubber. First, it does not introduce extra voltage and current stress on the main switch. Second, it provides soft-switching conditions for the main switch over wide input and load range. Third, it limits the turn ON current of the main switch resulting from the reverse recovery current of the output diode. The operating principle of the proposed snubber and procedure of designing the component values are given. A comparative study into the performance characteristics between the Converter without snubber and the proposed snubber is performed. Closed loop voltage feedback is used to regulate the output of the converter. The proposed boost converter ensured reliable operation and a high power efficiency under ±10% of input voltage variation. Circuit simulation and implementation is done in NI Multisim Version 13.**

***Index Terms*— Boost Converter, DC-DC Power Conversion, Hard and Soft Switching, LED Display, Snubbers.**

I. INTRODUCTION

The switching power supply market is flourishing quickly in today's high-tech world. Design engineers aren't always supplied with the desired amount of voltage they need in order to make their design work. Adding an additional voltage supply to a design is not always cost efficient. It increases the need of efficient converters in an economical way. Advanced technologies, such as LED BLUs, hybrid-electric vehicles, data communication industries, battery-electric, and hybrid-fuel cell vehicles rely on high-power DC-DC boost converters to interconnect and manage their power sources Accordingly, DC-DC boost converters for these applications should deliver the required power efficiently, reliably, and with higher power density. As a result of these research efforts, soft-switched DC-DC boost converters have emerged as a viable candidate for high efficiency DC-DC converters.

A DC-DC boost converter is also known as a step up converter. It is a DC-to-DC power converter where output voltage is greater than its input voltage. Output current is smaller than the source current since power (P=VI) has to be conserved.It consists of simple components like inductor, capacitor, diode, MOSFET or BJT or IGBT switch and load connected at the output. Battery is used to give the input supply. Inductor acts as the energy storage element and capacitor connected at the output of the converter reduces output voltage ripple.The SMPS (switched-mode power supply) switch must be turned ON and OFF quickly and have low losses in order to attain high efficiency. A snubber circuit with soft switching, consisting of a combination of inductor and capacitor is used to reduce reverse recovery current of a diode which reduces losses and thereby, increase the efficiency of the dc-dc boost converter [1]-[5].The DC-DC boost converters are small, lightweight, efficient, simply constructed and hence can be implemented in small inexpensive circuits. DC–DC boost converters have a wide range of applications. They are used in battery power systems to increase the voltage and reduce the number of cells in the battery. They are of great use in hybrid electric vehicles and lighting systems. They are used in portable lighting system like LEDs and they can yield higher voltages to operate cold cathode fluorescent tubes in LCD backlights and some flashlights.In this paper a closed loop boost converter with high efficiency using snubber circuit is proposed. The operation and switching techniques of a DC–DC boost converter are given in Section II. The theoretical operation of the snubber circuit used to increase efficiency is given in Section III. The design considerations are given in Section IV. The experimental set up is given in Section V. The simulation results are given in Section VI and the conclusion is given in Section VII.

II. DC-DC BOOST CONVERTER

A. Operation

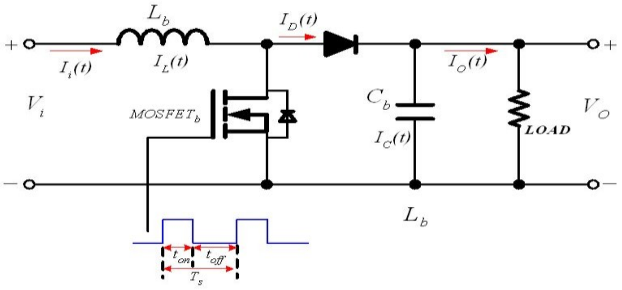

Fig. 1. Equivalent circuit of boost converter using MOSFET.

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The DC-DC boost converter is operated under the following cases [6]:
(a) Switch is closed:Current flows in the clockwise direction through the inductor. The inductor stores energy by creating a magnetic field. It results an increase in the inductor current.Polarity of inductor is + -
(b) Switch is open:Now, as the impedance is higher current will be decreased. The magnetic field created in the previous case is ruined so as to retain the flow of current towards the load.Polarity of inductor is - +
Now the two sources are in series. The energy is transferred into the capacitor. This results in a higher voltage to charge the capacitor through diode D.A DC-DC boost converter has two modes of operation, continuous and discontinuous.

B. Soft Switching Techniques

It is desirable for a power converter to perform at high efficiencies.High frequency operation of the converter is desired to make the converter more efficient and lightweight. . However, high frequency operation results in higher switching losses and higher switching stresses caused by stray inductance and junction capacitance. Hence, soft switching is preferred over hard switching [7]-[10]. The following are the advantages of soft switching:

1) Lower switching losses due to smaller overlap of switch voltage and current.
2) Lower dv/dt and di/dt and thus lower voltage spike and EMI emissions.
3) Higher reliability due to reduced stresses on the switching components.
4) Reduced voltage and current ratings for the devices resulting in smaller reactive elements.

Soft switching for the power devices can be achieved either by zero-voltage switching (ZVS) or zero-current switching (ZCS). ZVS consists of turning on the switches while the voltage across them is zero. ZCS consists of turning off the switches when the current through them is zero. Common to all approaches of soft switching is the use of reactive elements to shape the current and voltage waveforms to achieve the necessary conditions for ZVS or ZCS.

III. OPERATION OF THE SNUBBER CIRCUIT USED

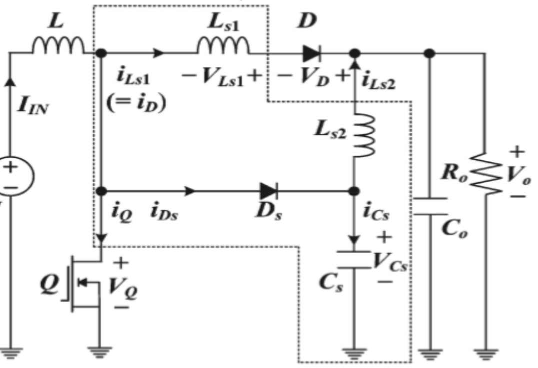


Fig. 2. DC-DC boost converter using passive snubber circuit.

This boost converter has a passive snubber circuit [11] that consists of two inductors L_{s1} and L_{s2}, diode D_s and capacitor C_s. Apart from that the conventional DC-DC boost converter consists of boost inductor L, boost switch Q, boost diode D and output capacitor C_o. L_{s1} and L_{s2} have inductance values much lesser than inductance value of L and the capacitance value of C_s is much smaller than the capacitance value of C.
A few assumptions are made for easy study of operation.

1) L and C_o are large enough that V_{IN} and L can be approximated as constant current I_{IN}.
2) Voltage of R_o andC_o can be approximated as constant voltage source V_o.
3) C_o, L_{s1} and L_{s2} are lossless.
4) C_o and On-state resistance of Q are neglected.

The proposed boost converter has a duty ratio D_r and switching period T_s. There are 5 periods of operation during T_s.

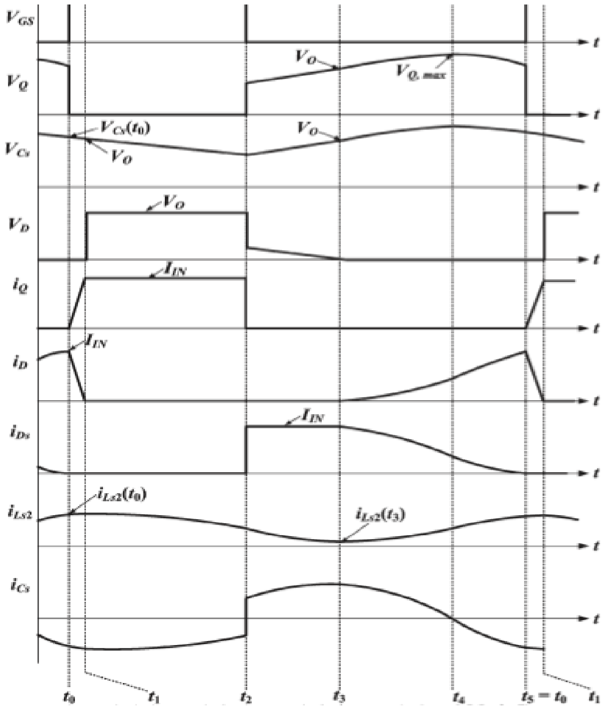


Fig. 3. Theoretical waveforms of boost converter using snubber circuit.

Period 1 [t_o – t_1]:It is assumed that right before t_0 Q is turned OFF. So, at t_0, Q is turned ON and current i_{Ds} has reached 0. D_s is turned OFF. Since V_0 applied across L_{s1} is constant, i_D starts to decrease linearly whereas i_Q increases linearly at the same rate since $i_Q + i_D = I_{IN}$, which is constant. C_s is discharged through L_{s2} to the load by i_{Ls2}. Hence, V_{Cs} decreases from V_{Cs} (t_0) to V_0.
*Period 2 [t_1 – t_2]:*Q remains ON. D_s remains OFF. Since i_D is 0 at t_1, D is turned off and hence, i_Q (t) becomes equal to I_{IN}. Also i_{Ls2} becomes i_{Ls2} (t_2) and V_{Cs} becomes V_{Cs} (t_2) at t_2.
*Period 3 [t_2 – t_3]:*After period 2, Q is turned off at t_2. D_s gets turned ON. D is still turned OFF. Now I_{IN} flows through D_s. i_{Ds}, whose value is equal to I_{IN} gets distributed as i_{Ls2} and i_{Cs}. Now, since voltage across L_{s1} and forward voltage of D_s are very small, $V_Q = V_C$ and $V_D = V_O – V_Q$. SO, V_Q increases gradually. Since current i_{Cs} charges capacitor C_s and V_{Cs} increases, hence, V_D decreases gradually at the same rate.V_Q increases to V_O at t_3 so, V_D falls to 0 and D starts conducting. i_{Ls2} reaches i_{Ls2} (t_3) and i_{Cs} reaches i_{Cs} (t_3).
*Period 4 [t_3 – t_4]:*Q stays OFF. D_s stays ON. At t_3 D gets turned ON. Because of the resonance of L_{s1}, L_{s2} and C_s, i_D increases gradually. I_{IN} courses through D and D_s. Current

i_{Ds} gets divided as i_{Ls2} and i_{Cs}. Current i_{Ls2} courses into R_o though $L_{s2.}$ C_s is charged by i_{Cs}. Hence, V_Q whose value is equal to V_{Cs}, is increased slowly. At $t_{4,}$ i_{Ls2} reaches i_{Ls2} (t_4); i_{Cs} becomes 0 and maximum voltage of Q becomes $V_{Q,max}$.

*Period 5 [$t_4 - t_5$]:*Q stays OFF. D_s stays ON. D gets turned ON. I_{IN} has two flow paths:

1) $V_{IN} - L_{s1} - D - R_o$
2) $V_{IN} - D_s - L_{s2} - R_o$

i_{Cs} has the flow path $C_s - L_{s2} - R_o$. It discharges V_{Cs}. Hence, $V_Q = V_c$ also gets decreased from $V_{Q,max}$to again V_{Cs} (t_0) at $t_{5.}$ Also, i_{Ls2} reaches i_{Ls2} (t_0) and i_D again becomes 0.

Circuit is again in period 1 now.

With ZCS turning ON of Q usage of L_{s1} one can control the turn off *di/dt* of D and also eradicate reverse recovery current of D_s.

IV. DESIGN SPECIFICATIONS

In the DC-DC boost converter employed for simulation in NI Multisim, the components used are designed as specified below [6].

The duty cycle for a DC-DC boost converter is given by

$$D = 1 - V_i / V_o$$

Here, in the formula*D* is the duty cycle, V_i is the input voltage and V_o is the output voltage

The boost inductance value should be more than L_{min} so the boost converter operates in continuous conduction mode. It is given by

$$L_{min} = [D.\ (1 - D)^2.\ R] / 2f_s$$

Here, in the formula*D* is the duty cycle, R is the output resistance and f_s is the switching frequency.

One can self-design the inductor using the relation

$$L = (d^2\ n^2) / (l + 0.45d)$$

Here, in the formula *L* is in micro Henry, *d* is in metres, *l* is in metres and *n* is the number of turns.

The output capacitor rating should be more than C_{min}. Capacitors with low equivalent series resistance should be used for better efficiency and performance. Parallel connection of capacitor can reduce equivalent series resistance. The boost capacitance value is given by

$$C_{min} = D / V_r.\ R.\ f_s$$

Here, in the formula, *C* is the minimum value of capacitance, *D* is the duty cycle, *R* is the output resistance and $V_{r.}$ is the output voltage ripple.

The load used here is a simple 4X4 LED panel. Each row consists of 4 LEDs. Each row needs a current of 10-15 mA, so, the entire LED panel would need 60 mA.

An electronic switch such as Power MOSFET is selected such that its voltage and current ratings are higher than the maximum input voltage and current.Diode is selected such as its reverse voltage rating should be high. It should have fast switching, low forward voltage drop, adequate average and peak current handling capacity and low reverse recovery.

V. EXPERIMENTAL SET UP

The proposed snubber circuit was simulated in NI Multisim Version 13.

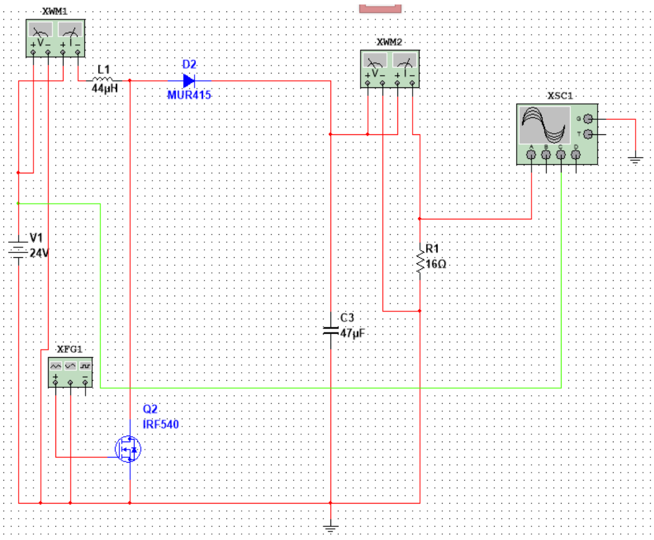


Fig. 4. DC-DC boost converter without snubber at 70W load.

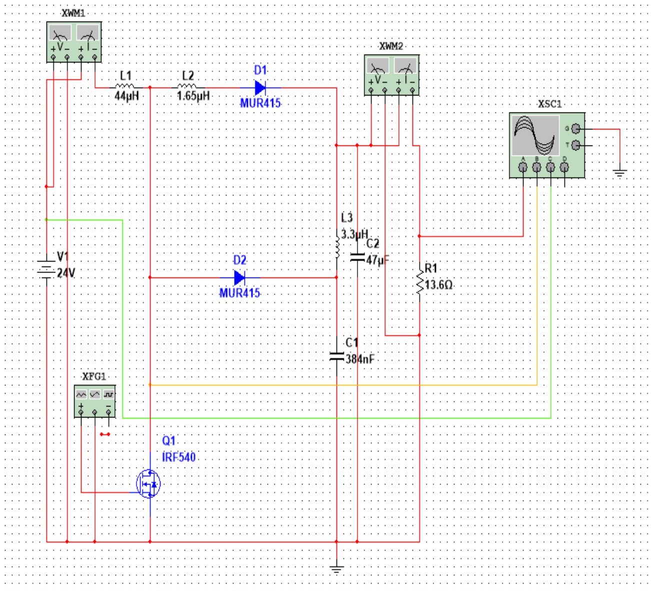


Fig. 5. DC-DC boost converter with snubber at 90W load.

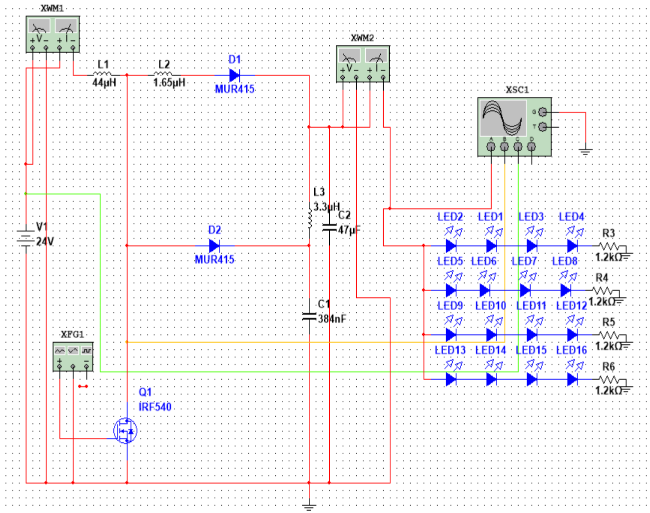
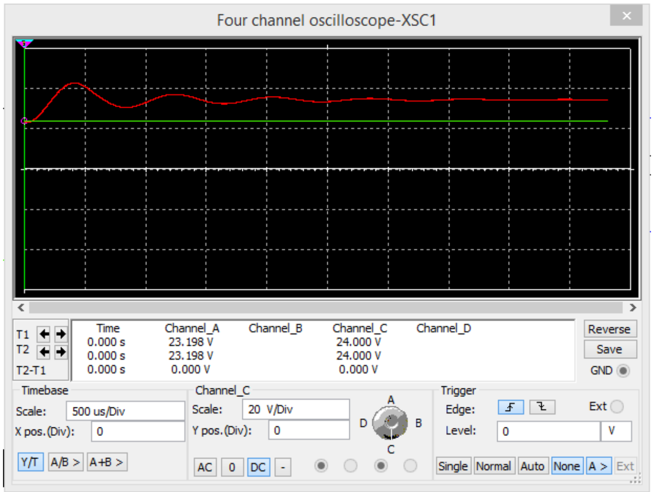


Fig. 6. DC-DC boost converter with LED lighting load.

VI. SIMULATION RESULTS

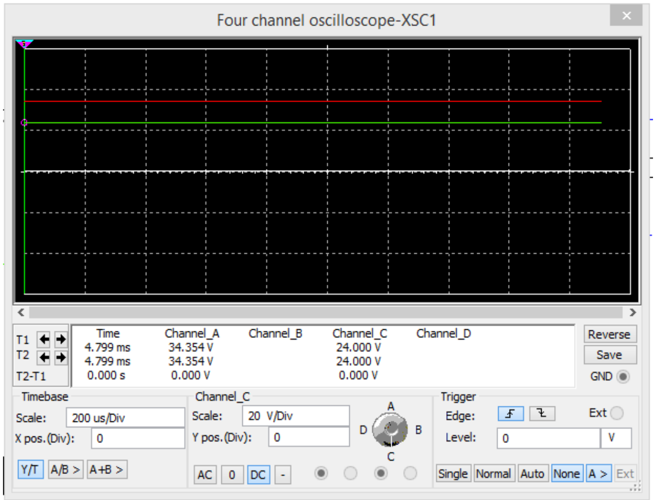
The simulations were done for ± 10% variation in input voltage and ± 20% variation in snubber components. This resulted in high efficiency of DC-DC boost converter.



	Time	Channel_A	Channel_B	Channel_C	Channel_D
T1	0.000 s	23.198 V		24.000 V	
T2	0.000 s	23.198 V		24.000 V	
T2-T1	0.000 s	0.000 V		0.000 V	

Timebase
Scale: 500 us/Div
X pos.(Div): 0
Channel_C
Scale: 20 V/Div
Y pos.(Div): 0
Trigger
Edge:
Level: 0 V

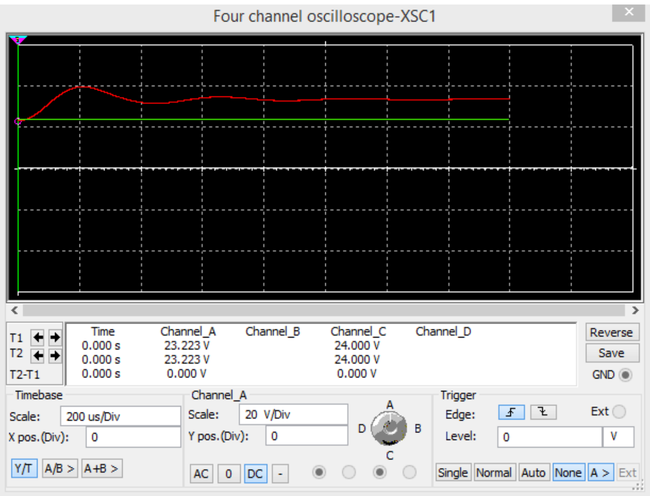
Fig. 7. Load voltage in transient state without snubber.



	Time	Channel_A	Channel_B	Channel_C	Channel_D
T1	4.799 ms	34.354 V		24.000 V	
T2	4.799 ms	34.354 V		24.000 V	
T2-T1	0.000 s	0.000 V		0.000 V	

Timebase
Scale: 200 us/Div
X pos.(Div): 0
Channel_C
Scale: 20 V/Div
Y pos.(Div): 0
Trigger
Edge:
Level: 0 V

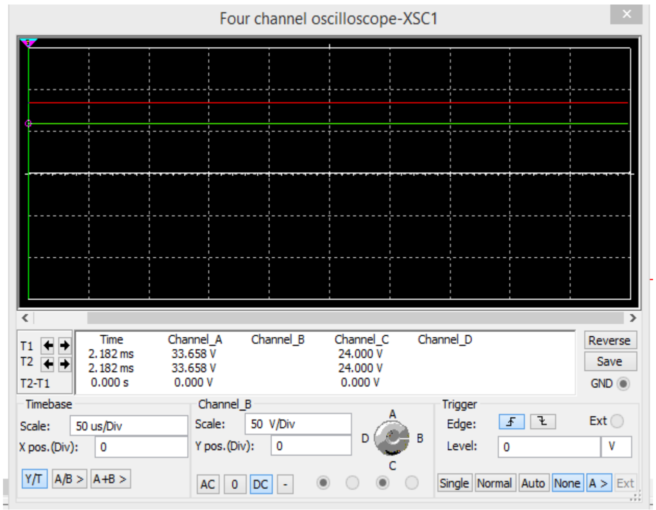
Fig. 8. Load voltage without snubber.



	Time	Channel_A	Channel_B	Channel_C	Channel_D
T1	0.000 s	23.223 V		24.000 V	
T2	0.000 s	23.223 V		24.000 V	
T2-T1	0.000 s	0.000 V		0.000 V	

Timebase
Scale: 200 us/Div
X pos.(Div): 0
Channel_A
Scale: 20 V/Div
Y pos.(Div): 0
Trigger
Edge:
Level: 0 V

Fig. 9. Load voltage in transient state with snubber.



	Time	Channel_A	Channel_B	Channel_C	Channel_D
T1	2.182 ms	33.658 V		24.000 V	
T2	2.182 ms	33.658 V		24.000 V	
T2-T1	0.000 s	0.000 V		0.000 V	

Timebase
Scale: 50 us/Div
X pos.(Div): 0
Channel_B
Scale: 50 V/Div
Y pos.(Div): 0
Trigger
Edge:
Level: 0 V

Fig. 10. Load voltage with snubber.

TABLE I
EFFICIENCY OF DC-DC BOOST CONVERTER WITHOUT SNUBBER AT DIFFERENT LOADS

Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)	Resistance (ohms)	Regulation (%)
24	34.364	77.862	73.511	94.42	16	21.77
24	34.357	81.374	77.018	94.64	15.3	21.89
24	34.256	91.398	86.469	94.50	13.6	21.71
24	34.214	106.923	101.078	94.53	11.6	21.61
24	34.145	124.024	117.117	94.43	9.98	21.81

TABLE II
EFFICIENCY OF DC-DC BOOST CONVERTER WITH SNUBBER AT DIFFERENT LOADS

Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)	Resistance (ohms)	Regulation (%)
24	33.407	72.439	69.864	96.44	16	11.03
24	33.495	76.049	73.313	96.34	15.3	11.48
24	33.346	84.779	81.751	96.42	13.6	10.39
24	33.117	98.030	94.551	96.45	11.6	11.7
24	33.167	112.490	108.233	96.22	9.98	11.82

TABLE III
Effect of Duty Cycle on DC-DC Boost Converter Without Snubber at 70W Load

Duty Cycle	Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)
0.2	24	29.086	69.527	65.873	94.64
0.32	24	34.236	71.273	67.483	94.61
0.4	24	39.025	70.555	66.714	94.55

TABLE IV
Effect of Duty Cycle on DC-DC Boost Converter With Snubber at 70W Load

Duty Cycle	Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)
0.2	24	28.607	66.374	63.380	96
0.32	24	33.417	72.439	69.864	96.44
0.4	24	38.204	66.265	63.841	96.34
0.6	24	58.168	68.381	65.783	96.2

TABLE V
Effect of Duty Cycle on DC-DC Boost Converter Without Snubber at 90W Load

Duty Cycle	Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output power (W)	Efficiency (%)
0.2	24	29.072	89.153	84.407	94.56
0.32	24	34.256	91.398	86.469	94.6
0.4	24	38926	90.363	85.374	94.47

TABLE VI
Effect of Duty Cycle on DC-DC Boost Converter With Snubber at 90W Load

Duty Cycle	Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)
0.2	24	28.404	83.688	80.480	96.16
0.32	24	33.346	84.779	81.751	96.42
0.4	24	37.880	83.554	80.234	96.10
0.6	24	57.800	88.886	83.643	96.09

TABLE VII
Effect of Duty Cycle on DC-DC Boost Converter Without Snubber at 120W Load

Duty Cycle	Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)
0.2	24	28.950	118.459	111.992	94.5
0.32	24	34.145	124.024	117.117	94.43
0.4	24	38.796	119.998	113.181	94.4

TABLE VIII
Effect of Duty Cycle on DC-DC Boost Converter With Snubber at 120W Load

Duty Cycle	Input Voltage (V)	Output Voltage (V)	Input Power (W)	Output Power (W)	Efficiency (%)
0.2	24	28.066	109.084	104.848	96.11
0.32	24	33.167	112.490	108.233	96.22
04	24	37.31	108.491	104.347	96.18

TABLE IX
Effect of Snubber Components of DC-DC Boost Converter at 70W Load

Component Value	Input Power (W)	Output Power (W)	Output Voltage (V)	Efficiency (%)	Resistance (ohms)
Normal	70.261	67.513	33.6	96.2	16.72
80% of L_{S1}	71.524	68.461	33.849	95.9	16.72
120% of L_{S1}	69.640	66.908	33.455	96.07	16.72
80% of L_{S2}	71.150	67.910	33.718	95.4	16.72
120% of L_{S2}	70.152	67.308	33.566	95.9	16.72
80% of C_S	70.740	67.811	33.656	95.85	16.72
120% of C_S	70.602	67.961	33.718	96.15	16.72

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TABLE X
EFFECT OF SNUBBER COMPONENTS OF DC-DC BOOST CONVERTER AT 90W LOAD

Component Value	Input Power (W)	Output Power (W)	Output Voltage (V)	Efficiency (%)	Resistance (ohms)
Normal	84.779	81.751	33.346	96.42	13.6
80% of L_{S1}	85.733	82.358	33.535	96.01	13.6
120% of L_{S1}	84.398	81.206	33.250	96.21	13.6
80% of L_{S2}	85.614	82.446	33.432	96.29	13.6
120% of L_{S2}	84.705	81.422	33.275	96.11	13.6
80% of C_S	85.656	82.207	33.450	95.97	13.6
120% of C_S	86.803	83.045	33.596	96.11	13.6

TABLE XI
EFFECT OF SNUBBER COMPONENTS OF DC-DC BOOST CONVERTER AT 120W LOAD

Component Value	Input Power (W)	Output Power (W)	Output Voltage (V)	Efficiency (%)	Resistance (ohms)
Normal	112.40	108.233	33.147	96.22	10
80% of L_{S1}	114.231	109.234	33.146	95.6	10
120% of L_{S1}	116.064	110.284	33.487	95.2	10
80% of L_{S2}	114.348	109.457	33.250	96	10
120% of L_{S2}	112	107.715	33.432	96.1	10
80% of C_S	112.643	108.464	33.275	96.19	10
120% of C_S	115.481	110.562	33.596	95.74	10

VII. CONCLUSION

A high efficiency and high performance closed loop DC-DC boost converter using a passive snubber circuit was proposed. Closed loop operation and the snubber circuit have helped in increasing the efficiency of the boost converter.Passive snubber circuit enabled ZCS turn ON for the boost switch, thereby, reducing reverse recovery losses of the diode and switching losses of the MOSFET. Electromagnetic interference noise produced at the instant of turn OFF switching has been decreased. Also, the thermal stress and current stress of the boost MOSFET switch and diode were reduced.Efficiency of this boost converter has a range of 96% to 98%, where as normal boost converter has a range of 93% to 94%. The current stress and thermal stress of boost switch and diode are decreased. The proposed boost converter ensured reliable operation and high power efficiency under ±10% variation in input voltage and ± 20% variation in snubber components. The entire schematic was designed and simulated in Multisim, which resulted in an efficiency of 96%.

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REFERENCES

[1] M. R. Amini and H. Farzanehfard, "Novel family of PWM soft-single-switched dc-dc converters with coupled inductors," *IEEE Trans. Ind. Electron.*, vol. 56, no. 6, pp. 2108-2114, Jun. 2009.

[2] R. H. Li, H. S. H. Chung, and A.T. Sung, "A passive lossless snubber cell with minimum stress and wide soft-switching," *IEEE Trans. Power Electron.*, vol. 25, no. 7, pp. 1725-1738, Jul. 2010.

[3] R. J. Wai and R. Y. Daun, "High step-up converter with coupled-inductor," *IEEE Trans. Power Electron.*, vol. 20, no. 5, pp 1025-1035, Sep. 2005.

[4] D. D.C. Lu. D. K. W. Cheng, and Y. S. Lee, "A single switch continuous conduction-mode boost converter with reduced reverse-recovery and switching losses," *IEEE Trans. Ind. Electron.*, vol. 50, no. 4, pp. 767-776, Aug. 2003.

[5] R. H. Li, H. S. H. Chung, and A.T. Sung, "Passive lossless snubber for boost PFC with minimum voltage stress and current stress," *IEEE Trans. Power Electron.*, vol. 25, no. 3, pp. 602-603, Mar. 2010.

[6] P. Sathya, Dr. R. Natarajan, "Design and Implementation of 12V/24V Closed loop Boost Converter for Solar Powered LED Lighting System," *International Journal of Engineering and Technology*, vol. 5, no. 1, pp. 254-264, Feb.-Mar. 2013.

[7] N. Mohan. T. Undeland, and W. Robbins, *Power Electronics: Converters, Applications, and Designs,* 3rd ed. New York: Wiley, 2003.

[8] E. Acha., V. Agelidis, O. Anaya-Lara, and T. Miller, *Power Electronic Control in Electrical Systems.* Woburn, MA:Newnes, 2002.

[9] S. Hui. And H. Chung, "Chapter 16:Resonant and soft-switching converters," in *Power Electronics Handbook*, M. Rashid, Ed. San Francisco, CA: Academic, 2006, pp. 405-449.

[10] River T. H. Li, Henry Shu-Hung Chung and Anson K. T. Sung, "Passivc lossless snubber for boost pfc with minimum voltage and current stress," *IEEE Trans. Power Electron.*, vol. 25, no. 3, pp. 602-613, Mar. 2010.

[11] Jae Jung Yun, Hyung-Jin Choe, Young-Ho Hwang, Yong-Kyu Park, and Bongkoo Kang, "Improvement of Power-Conversion Efficiency of a Dc-Dc Boost Converter Using a Passive Snubber Circuit," *IEEE Trans. Power Electron.*, vol. 59, no. 4, pp. 1808-1814, Apr. 2012.

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