A NOVEL TOPOLOGY FOR THE ENHANCEMENT OF SEPIC CONVERTER USING SNUBBER CIRCUIT

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ABSTRACT

A novel topology for the enhancement of SEPIC converter using snubber circuit is presented in this paper. There are different snubber circuits available in power electronics which reduces the switching losses during turn-on and turn-off. Here passive regenerative snubber circuit is used to extract the maximum output in the converter. For achieving this condition, the technique used is non-dissipative snubber circuit. The working of non-dissipative snubber circuit based SEPIC converter is explained. The simulink models of the boost converter, ordinary SEPIC converter and proposed snubber circuit based SEPIC converter are analysed and simulated in MATLAB Simulink. The output voltage and current results of the different simulink models of these converters are summarized. The behaviour of the different converters is found which shows that snubber circuit enhances the efficiency of the system in comparison of the other converters.

KEYWORDS: *Dc-dc converters, SEPIC converter, MATLAB Simulink, Snubber circuits*.

I. INTRODUCTION

Switching transients generates the switching losses in dc-dc converters during turn-on and turn-off of power semiconductor devices. In power semiconductor devices, a surge current flows through the switches, caused by the reverse-recovery current of the freewheeling diode during the turn-on process which is the source of turn-on loss. Similarly, fast increase of the switch voltage during the turn-off process occurs which is the source of turn-off loss. A passive lossless snubber with boost converter has been built to verify the principle of operation and the theoretical analysis. The general snubber cell is the combination of a turn-on and turn-off snubber circuits. Energy recovery is achieved by passive components only.

Energy regenerative snubber is used to reduce the converter switching losses aiming to improve the overall system efficiency. In order to reduce the switching losses of the SEPIC converter, a regenerative snubber composed of capacitor, inductor and diode is used. It is important to observe that, although four extra elements are added to the circuit in order to implement the regenerative snubber, their volume and cost should be reduced, since the energy involved is very low when compared with the system power rating. Moreover, the efficiency improvement would probably be better in applications where the switching frequency is higher [1], [2]. A lighting system using a SEPIC converter is used to drive and control power LEDs currents with energy regenerative snubber for reducing the converter switching losses and to improve the system efficiency. SEPIC converters are capable of feeding loads that require low DC voltage level in systems requiring high power factor. By using an energy regenerative snubber it is possible to improve the system efficiency when compared to the employment of a classical snubber. SEPIC converters which uses tapped inductor, a charge pump and an inductor less regenerative snubber is used to attain a high DC step-up at high efficiency. This converter has the advantage of continuous input current, which can be helpful in attaining accurate tracking of the maximum power point of solar panels.

Also SEPIC derived high step-up converter utilise tapped inductor and charge pump techniques to achieve high step-up gain and a lossless inductor less snubber to lower the voltage stress and attain zero-voltage switching and high efficiency which is derived from a traditional SEPIC converter. A passive regenerative snubber contributes to low voltage stress and zero switching loss. Furthermore, the voltage across the rectifier diode is limited to the output voltage, which results in a reduced voltage stress of the device. For these reasons the SEPIC converter with snubber is a viable alternative for implementing renewable energy conversion systems, such as photovoltaic and fuel cell applications [3]- [6]. A soft switching active snubber is used to reduce the turn-off losses of the IGBT in a current-mode controlled buck converter. This modification provides zero-voltage switching for the IGBT. Hence it reduces the high turn-off losses of the IGBT due to the high transients. The proposed snubber uses an auxiliary switch to discharge the snubber capacitor. This auxiliary switch also operates at zero-voltage and zero current switching. The size of the auxiliary switch compared to the main switch makes this snubber a good alternative to the conventional snubber or even to passive low-loss snubbers.

To operate the IGBT at high frequencies and recovery of part of the energy stored in the snubber capacitor during the turn-off, soft switching active snubber circuits are used. The PWM technique is praised for its high power capability and ease of control. However, the semiconductor devices experience voltage and current stresses during the turn-on and turn-off transitions. The resonant technique on the other hand, allows the semiconductor devices to operate at zero-voltage and zero-current switching during turn-on and turn-off. The soft switching snubbers for converters that are composed of basic dc/dc converters makes a good alternative to its passive low-loss counterpart. Thus, the efficiency of the converter is improved due to the reduction in switching losses at turn-on and turn-off [7]- [9]. An active or passive clamp action is required necessary in isolated converter such as SEPIC converter for high voltage stress in the main switch due to transformer leakage inductance. The common passive solution based on a snubber. The voltage multiplier technique is applied to the classical SEPIC circuit obtaining new operation characteristics as low switch voltage operation and high static gain at low line voltage. The new configuration also allows the reduction of the losses associated to the diode reverse recovery current and soft-commutation is obtained with a simple regenerative snubber circuit.

In order to obtain a reduction of the diode reverse recovery current problem and also to obtain turn-on and turn-off soft-switching for all input voltage range and output power variation, a regenerative snubber circuits is used. The average current mode control is used for the classical boost converter and also for the new converter and the dynamic response obtained with both converters is approximately the same [10], [11]. A bridgeless active-clamp power factor correction isolated SEPIC converter uses the bridgeless topology to reduce the use of the rectifier diodes and improve the efficiency. The input current of the converter is designed to obtain a high power factor. The active-clamp topology can achieve the ZVS for all switches of the converter and it can also be as the snubber to reduce the spike induced by the leakage inductance of the transformer [12]- [14].

Several topological alternatives for using a magnetically coupled regenerative turn-on and turnoff snubber configuration applied to the dc-dc converters operating in continuous conduction mode which uses the main core of the converter to build the resonant inductor. In addition to reducing the stresses in the switch, providing soft transitions in its turn-off voltage and turn-on current, it transfers the energy stored in the snubber capacitor to the output (load) or input. In most applications such an oscillation should be avoided because it leads to increased noise and reduced efficiency and reliability. It is important, therefore, to know the conditions where subharmonic oscillation appears. A buck converter can be modelled as a square-wave generator with a linear feedback, and harmonic balance analysis can be applied to obtain good dynamic conditions [15], [16]. In a zero-ripple input current high step-up boost-SEPIC converter with reduced switch voltage stress to overcome some drawbacks of the conventional cascaded boost-SEPIC converter, the input current ripple is significantly removed by the auxiliary circuit at the boost stage and the voltage gain is more increased by using turn ratio of a coupled inductor. For a non-isolated high step-up converter, the combination of a boost converter with a series output module is investigated. As a solution to supplement the insufficient step-up ratio and distribute a voltage stress of a classical boost converter, a SEPIC-integrated boost converter, which provides an additional step-up gain.

Since the boost converter and the SEPIC converter share a boost inductor and a switch, its structure is simple and uses the voltage-doubler characteristics. A comparison of proposed method with the classic SEPIC converter shows that the new converters can either provide reduced voltage stress on the semiconductors for the same output voltage level or supply double the gain of the output voltage with the same voltage stress. The new voltage-doubler SEPIC provides a high power factor with no current control and they can be applied in order to improve the static gain of the structure, which can make the SEPIC rectifier suitable for applications that require a high voltage level [17]- [19].

The main use of snubber circuit is protection of the power semiconductor device. Various techniques with snubber circuits are used for the improvement of switching losses in the past by many researchers. In this paper, we are making an attempt to solve the problem of switching losses by a proposed snubber circuit. The proposed snubber consists of capacitor, inductor and diode combinations to achieve the high efficiency. The new technique enhances the SEPIC converter using proposed passive snubber circuit.

II. CIRCUIT DIAGRAMS OF DIFFERENT DC-DC CONVERTERS

There are various types of dc-dc converters which are used for the conversion from fixed dc voltage to variable dc voltage. In this paper boost converter, SEPIC converter and SEPIC converter with snubber circuit are used for the study purpose. The brief description of these converters with circuit diagrams are as follows:

2.1 BOOST CONVERTER

The boost converter is similar to buck converter structure wise, only the difference is that it has components arranged in different manner. The output of boost is always greater than input voltage therefore the boost converter is used when higher output voltage is required than the input voltage.

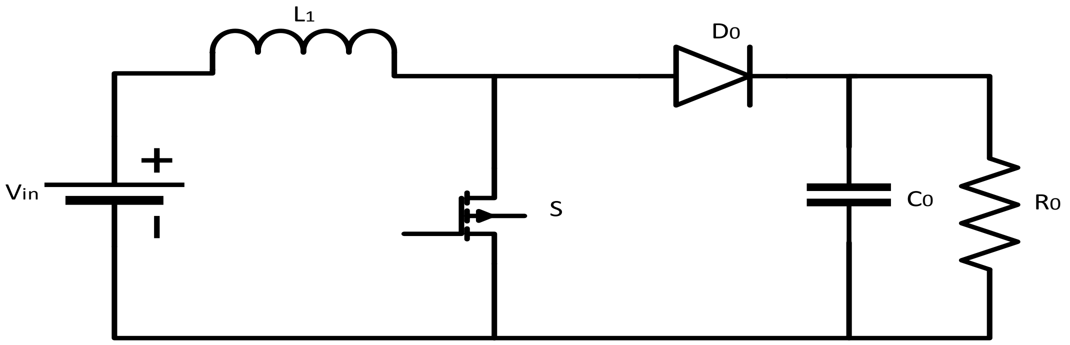

Figure 1. Circuit diagram of Boost Converter

It is also known as step-up converter because the voltage across inductor adds to the input supply voltage to step-up the voltage above input voltage.

2.2 SEPIC CONVERTER

Single ended primary inductor converter (SEPIC) is a type of converter that allows the electrical potential i.e. voltage at its output to be greater than or less than to that at its input. The output of the SEPIC converter is controlled by the duty cycle of the switch. The SEPIC converter exchanges energy between the capacitors and inductors in order to convert from one voltage to another. The amount of energy exchanged is controlled by switch S. The energy to increase the current comes from the input source.

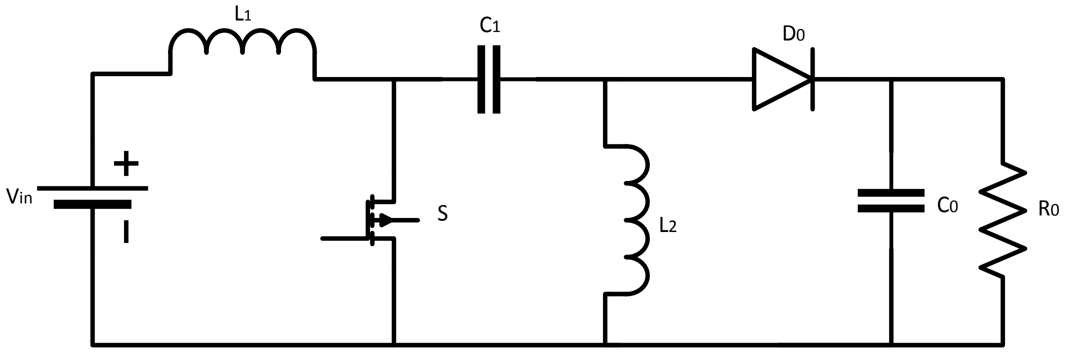

Figure 2. Circuit diagram of SEPIC converter

2.3 SEPIC CONVERTER WITH SNUBBER CIRCUIT

The passive snubber circuit with SEPIC converter is obtained by including the inductor, capacitor and diode combinations which enhances the voltage output of the SEPIC converter.

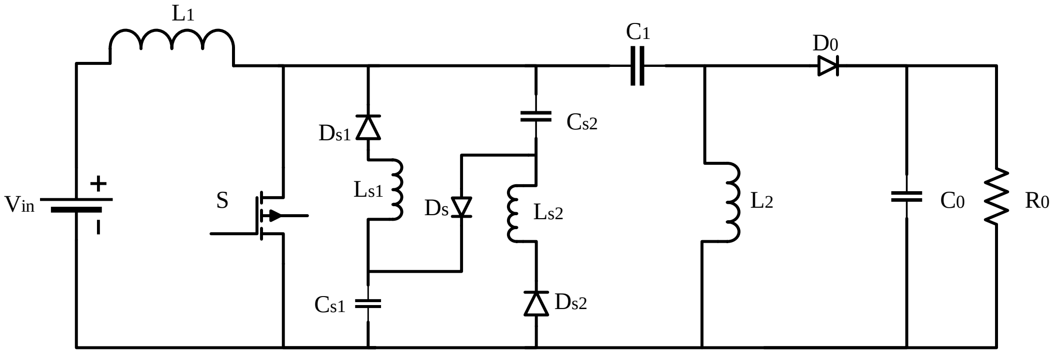

Figure 3. Circuit diagram of SEPIC converter with Snubber Circuit

III. WORKING OF THE SEPIC CONVERTER WITH SNUBBER CIRCUIT

Different snubber circuits are used to modify the SEPIC converter which reduces the switching losses in comparison of ordinary SEPIC converter like as R-C snubber circuit, R-C-D snubber circuit, L-C-D snubber circuit and many more. The L-C combination provides the smooth operation in comparison of R-C-D snubber circuit. The working of the proposed SEPIC converter with snubber circuit is divided in 7 steps as follows:

3.1. STEP-1

In this step the switch S is turn ON. The input inductor L_1 is charged through S. The voltages across C_{s1} and C_{s2} are positive, making diodes D_{s1} and D_{s2} conduct, charging inductors L_{s1} and L_{s2}. The output diode D_o is blocked and load is maintained by the output capacitor C_o.

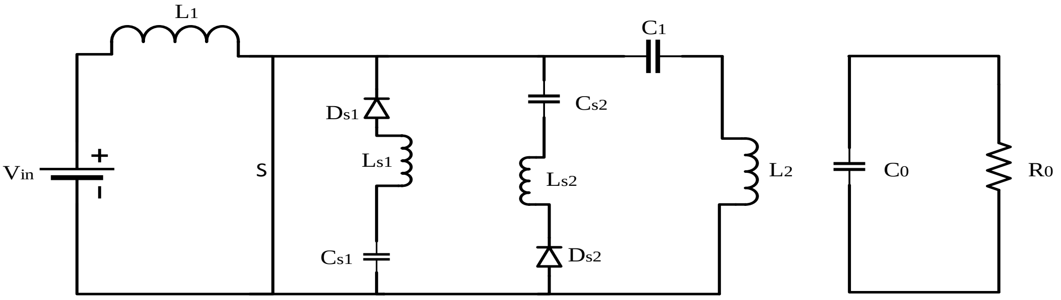

Figure 4. Working of SEPIC converter with snubber circuit

3.2. STEP-2

At the end of the step-1 all the energy stored in snubber capacitors is transferred to the snubber inductors. When all the energy is transferred, the diode D_s starts conduct keeping the currents in L_{s1} and L_{s2} in freewheeling through the switch S.

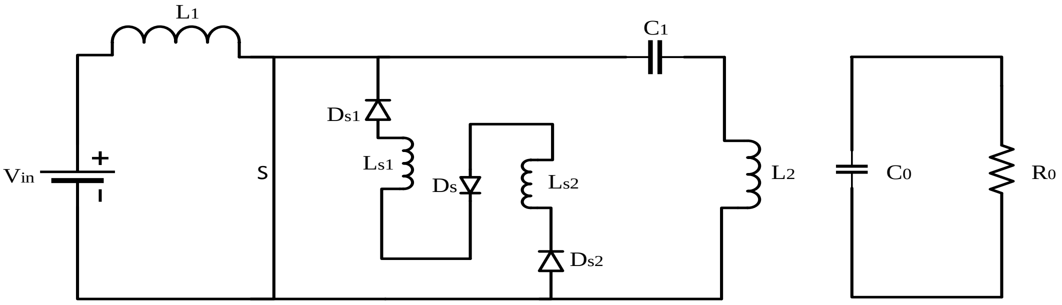

Figure 5. Working of SEPIC converter with snubber circuit

3.3. STEP-3

S is switched OFF in the end of the second step, starting the third step. Inductor L_2 charges C_{s1} and C_{s2} through D_s which creates a path for the currents through L_1, L_{s1} and L_{s2}.

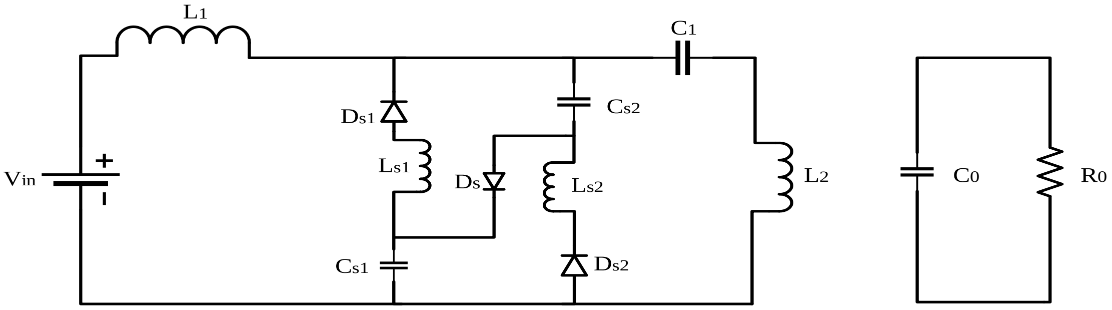

Figure 6. Working of SEPIC converter with snubber circuit

3.4. STEP-4

In this step diode D_o starts to conduct. During this step, the voltage across C_{s1} and C_{s2} continues to rise until all the energy stored in L_2 is transferred, blocking D_s and starting the next step.

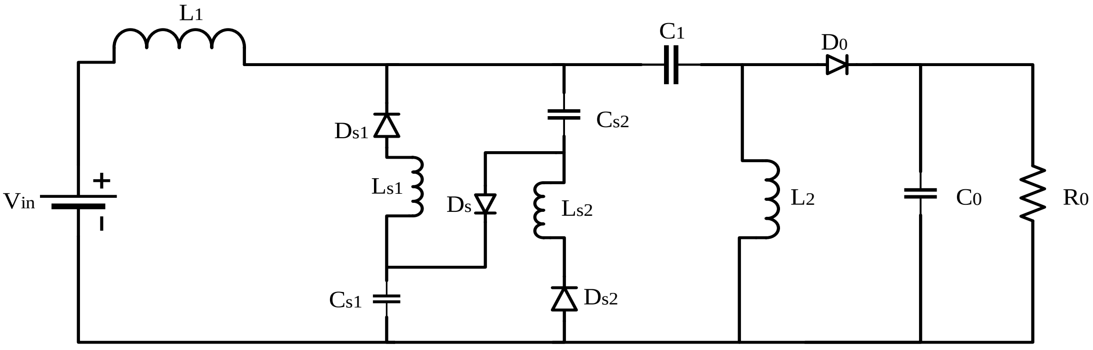

Figure 7. Working of SEPIC converter with snubber circuit

3.5. STEP-5

When all the energy stored in L_2 is transferred to the snubber D_s blocks starting the fifth step. In the end of the fifth step all the energy stored snubber inductors is transferred to snubber capacitors.

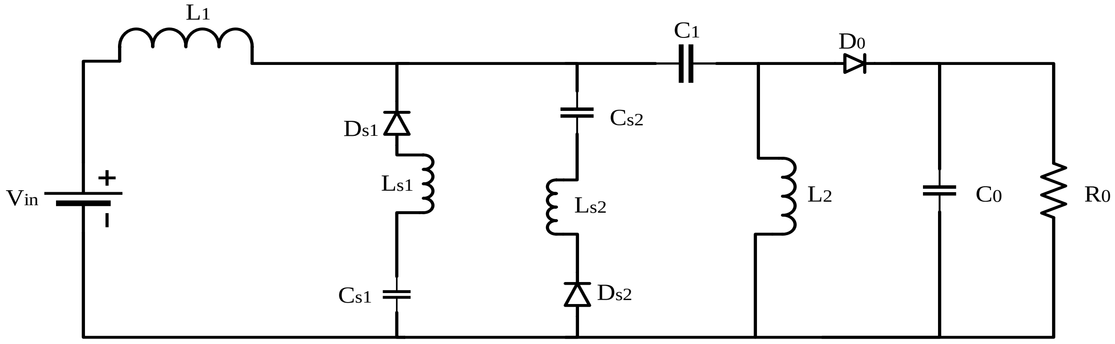

Figure 8. Working of SEPIC converter with snubber circuit

3.6. STEP-6

As currents in snubber inductors are zero, D_{s1} and D_{s2} are blocked in this step. The snubber is not conducting in this step. The normal SEPIC operation remains until all the energy stored in the input inductor is transferred to the output.

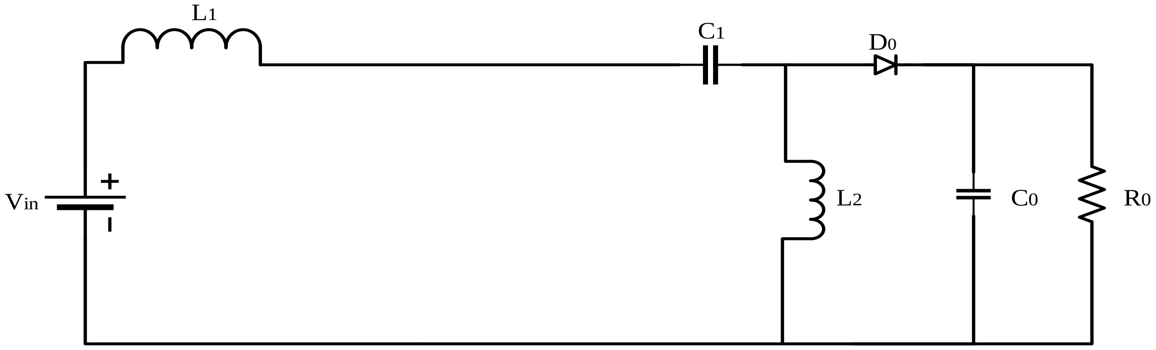

Figure 9. Working of SEPIC converter with snubber circuit

3.7. STEP-7

In this step output diode is blocked. The load is supplied by C_o. As the voltage across the snubber capacitors is larger than the voltage across S, diodes D_{s1} and D_{s2} are forward biased. The current through the snubber inductors start to grow, decreasing the voltage across snubber capacitors. This remains active until S is turned ON again, restarting the cycle.

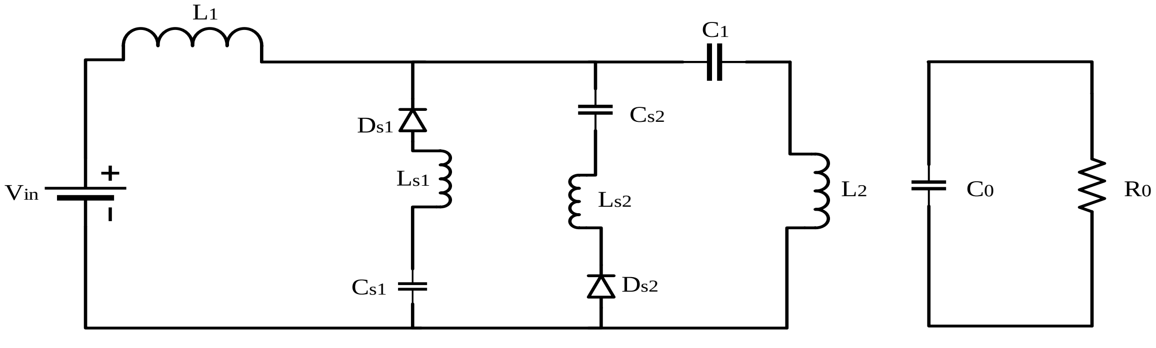

Figure 10. Working of SEPIC converter with snubber circuit

IV. SIMULINK MODELS AND RESULTS

The various simulink models of different converters used in this paper and their simulated results are as follows:

4.1 SIMULINK MODELS

The various parameters used in simulink models of various converters are shown in Table.1.

Table. 1 Model Parameters

S.No.	Model Parameters	Parameters Value
1	Input voltage, V_i	24V
2	Inductor, L_1	1mH
3	Inductor, L_2	500µH
4	Inductor, Ls_1 & Ls_2	500mH
5	Capacitor, C_1	660nF
6	Capacitor, Cs_1 & Cs_2	10pF
7	Capacitor C_o	2000µF
8	Switching frequency, f_s	48kHz

The various simulink models are as follows:

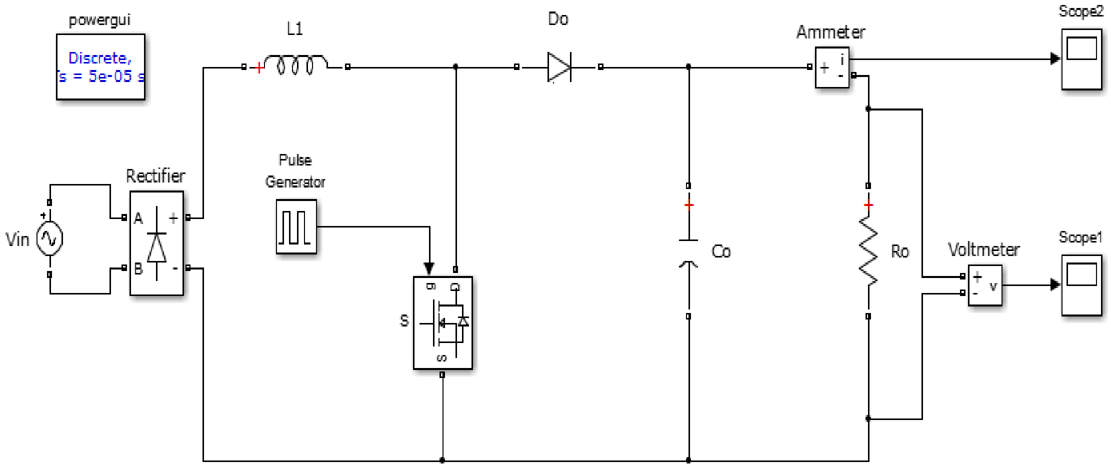

Figure 11. Simulink model of Boost converter

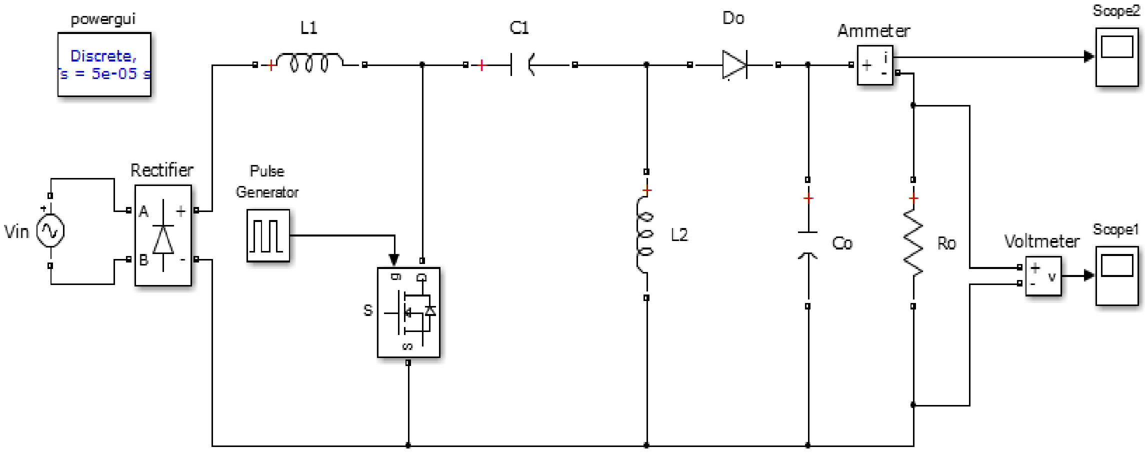

Figure 12. Simulink model of SEPIC converter

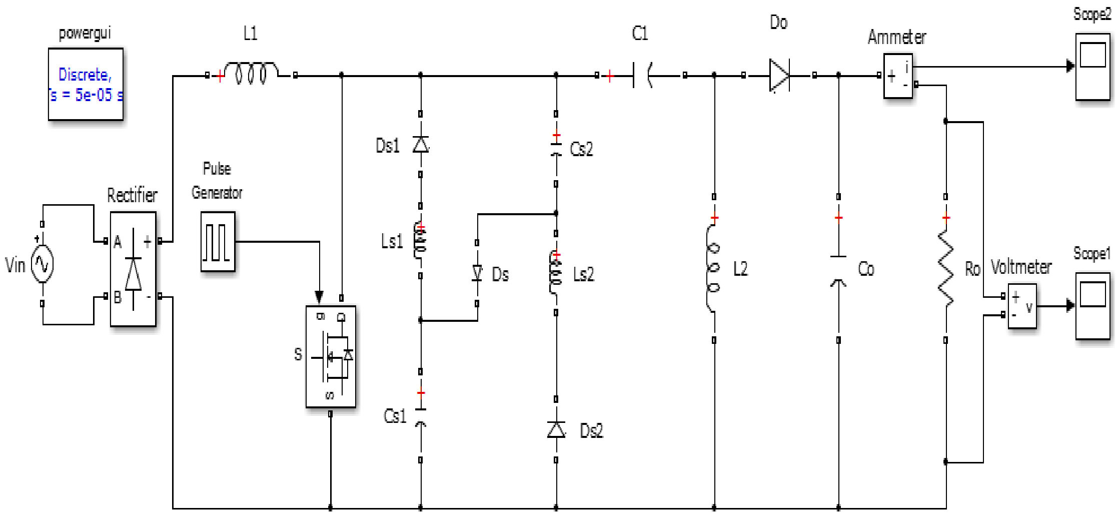

Figure 13. Simulink model of proposed SEPIC converter with Snubber Circuit

4.2 SIMULATED RESULTS

The different simulink models of various converters are simulated in MATLAB simulink and results are obtained. The various waveforms for the output voltages and currents of the boost converter, SEPIC converter and SEPIC converter with snubber circuit are as follows:

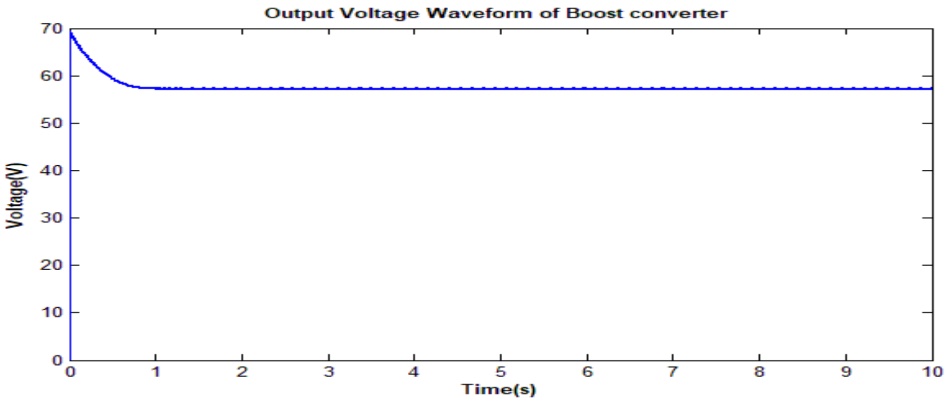

Figure 14. Output voltage waveform of Boost converter

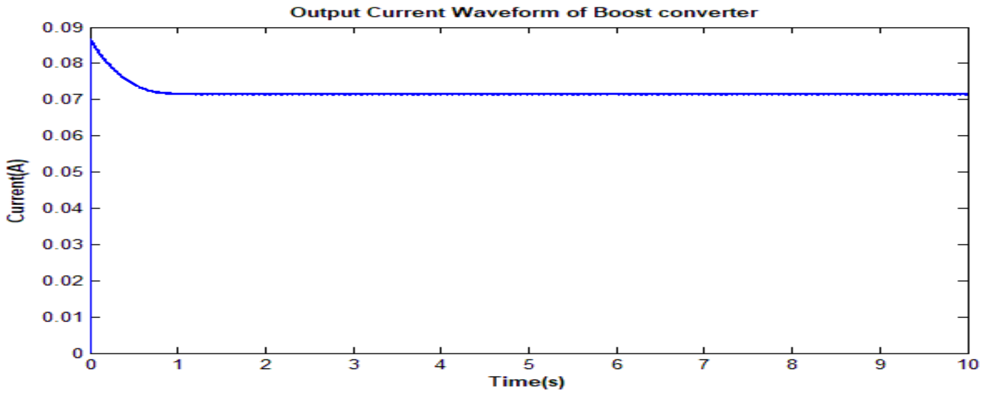

Figure 15. Output current waveform of Boost converter

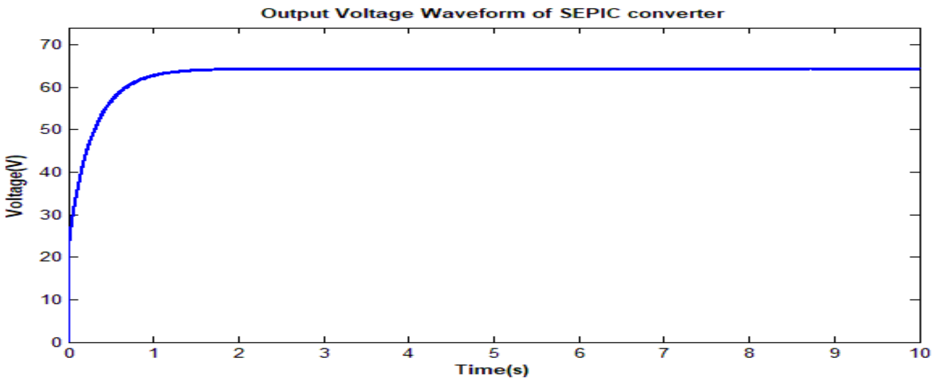

Figure 16. Output voltage waveform of ordinary SEPIC converter

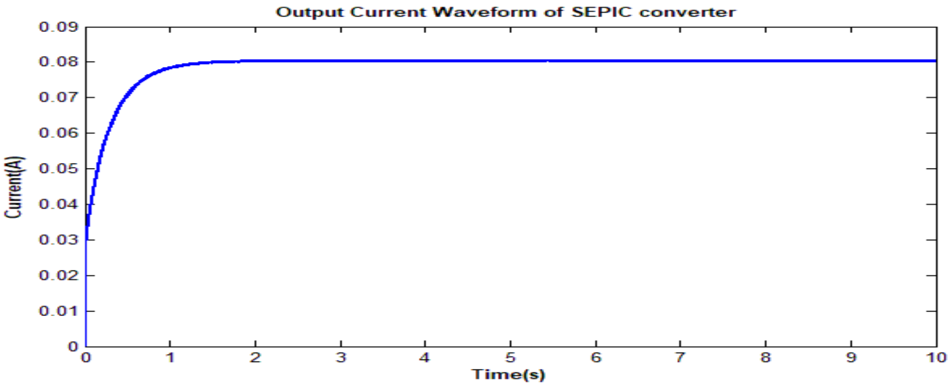

Figure 17. Output current waveform of ordinary SEPIC converter

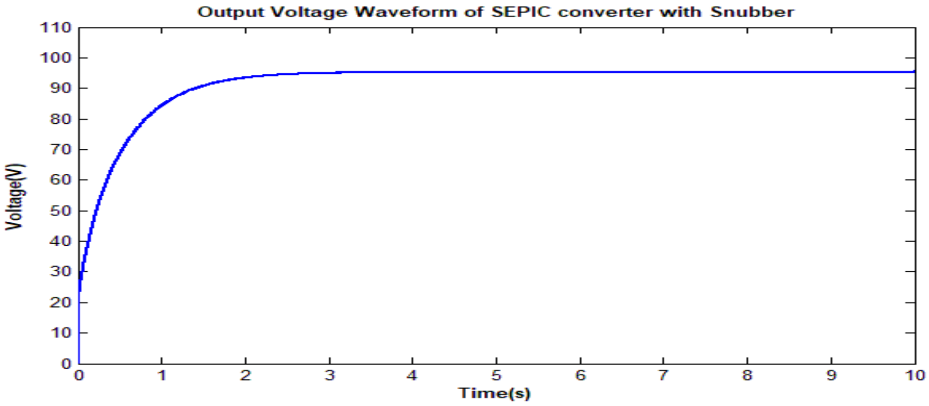

Figure 18. Output voltage waveform of SEPIC converter with snubber circuit

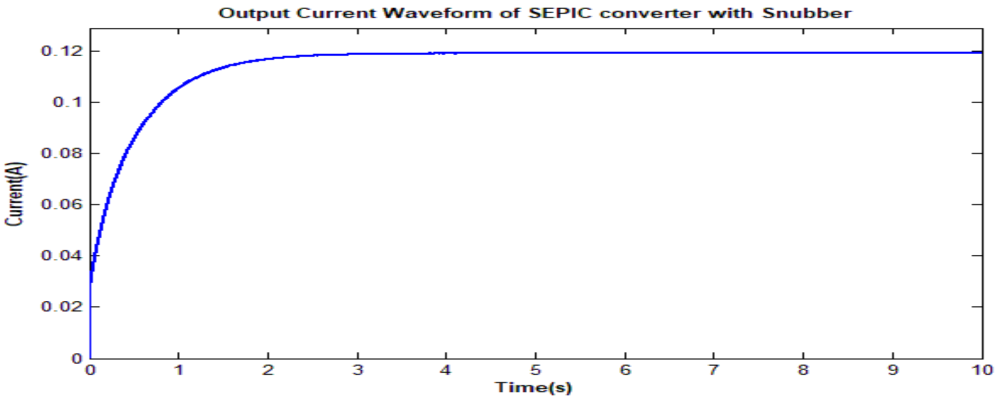

Figure 19. Output voltage waveform of SEPIC converter with snubber circuit

The result comparison of boost converter, ordinary SEPIC converter and SEPIC converter with snubber circuit is done according to the results obtained. The comparison of output voltages and currents of these converters is shown in Table.2.

Table. 2 Comparison between different converters

S.No.	Parameters	Converters		
		Boost	**Ordinary SEPIC**	**SEPIC with Snubber**
1	Input voltage	24V	24V	24V
2	Output voltage	57V	64V	95V
3	Output current	0.07A	0.08A	0.11A

V. CONCLUSIONS

In the present paper, different converters (boost, ordinary SEPIC and SEPIC with snubber circuit) model has been proposed and simulated to obtain the behaviour of output voltages and currents. It is clear that snubber circuit enhances the circuit operation, reducing switching losses and stress on elements achieving higher switching frequency. The snubber circuits can be mainly classified on two big categories: active and passive snubbers. Active snubber reduces switching losses but they need extra circuitry to control the active switch making more complex circuits. Passive snubbers are relatively simple to design and they can reduce switching losses so the design needs to be chosen between dissipative or non-dissipative snubbers. Dissipative Snubbers have fewer components and are relatively less complex but are less efficient, than non- dissipative snubbers because non-dissipative snubbers reuse the energy stored on snubber elements to turn it back to the source, sending it to the load or using this energy to prepare to the next transition of the waveform.

The behaviour of the boost converter, ordinary SEPIC converter and proposed SEPIC converter model with Snubber Circuit has been analysed. In the present time, SEPIC converters are widely used in various industrial and commercial applications. These converters provide well controlled and regulated dc to dc conversion. These converters provide comfortable and flexible operation of the system. SEPIC converter based products operate from batteries which benefits most from the wide ranging step down and step up operating modes of the SEPIC topology. Therefore, we can say that proposed SEPIC converter with snubber circuit is more efficient than the boost converter and ordinary SEPIC converter as output voltage of modified SEPIC converter is more than the output voltage of boost converter and ordinary SEPIC converter. Thus the behaviour of the SEPIC converter is enhanced with the help of snubber circuit.

VI. FUTURE SCOPE

There are various devices which require variable dc supply. SEPIC converter provides step up as well as step down voltage. The proposed SEPIC converter can be implemented to obtain high static gain in different dc-dc converters to obtain high efficiency.

REFERENCES

[1]. Tseng, C.J. & Chen, C.L., (1998) “A passive lossless snubber cell for non-isolated PWM DC/DC converters”, IEEE Transactions on Industrial Electronics, Vol. 45, No. 4, pp593-601.

[2]. Agostini, B.E., Font, C.H.I. & Nascimento, C.B., (2016) “Dimmable flicker-free power LEDs lighting system based on a SEPIC rectifier using a regenerative snubber”, IET Power Electronics, Vol. 9, No. 5, pp891-899.

[3]. Agostini, B.E., Font, C.H.I. & Nascimento, C.B., (2014) “A SEPIC-energy-regenerative-snubber with linear current regulator for power LEDs”, 11th IEEE/IAS International Conference on Industry Applications, pp1-6.

[4]. Abramovitz, A., Yao, J. & Smedley, K., (2014) "Derivation of a family of high step-up tapped inductor SEPIC converters", Electronics Letters, Vol. 50, No. 22, pp1626-1628.

[5]. Yao, J., Abramovitz, A. & Smedley, K., (2015) “Analysis and Design of Charge Pump-Assisted High Step-Up Tapped Inductor SEPIC Converter with an Inductorless Regenerative Snubber”, IEEE Transactions on Power Electronics, Vol. 30, No. 10, pp5565-5580.

[6]. Yao, J., Abramovitz, A. & Smedley, K., (2014) “High step-up tapped inductor SEPIC converter with charge pump cell”, IEEE Energy Conversion Congress and Exposition, pp2303-2309.

[7]. Elasser, A. & Torrey, D.A., (1995) “Soft switching active snubbers for DC/DC converters”, Applied Power Electronics Conference and Exposition, Vol. 1, pp483-489.

[8]. Torrey, (1996) “Soft switching active snubbers for DC/DC converters”, IEEE Transactions on Power Electronics, Vol. 11, No. 5, pp710-722.

[9]. Tsen,g C.J. & Chen, C.L., (1998) “Passive lossless snubbers for DC/DC converters”, Applied Power Electronics Conference and Exposition, Vol. 2, pp1049-1054.

[10]. Tibola, G., Lemmen, E. & Duarte, J.L., (2016) “Passive regenerative snubber cell applied to isolated DCM SEPIC converter”, IEEE 8th International Power Electronics and Motion Control Conference, pp2779-2786.

[11]. Melo, P.F.D., Gules, R., Romaneli, E.F. & Annunziato, R.C., (2009) “A soft-switching universal-input voltage HPF rectifier implemented with a modified SEPIC converter”, Brazilian Power Electronics Conference, pp948-955.

[12]. Chen, Y.T. & Mo, S.Z., (2013) “A bridgeless active-clamp power factor correction isolated SEPIC converter with mixed DCM/CCM operation”, 1st International Future Energy Electronics Conference, pp1-6.

[13]. V, V. & S, J., (2015) “Commutation Torque Ripple Reduction in BLDC Motor Using Modified SEPIC converter and Three-level NPC inverter”, IEEE Transactions on Power Electronics , No.99, pp307-312.

[14]. Melo, P.F.D., Gules, R., Romaneli, E.F. & Annunziato, R.C., (2010) “A Modified SEPIC Converter for High-Power-Factor Rectifier and Universal Input Voltage Applications”, IEEE Transactions on Power Electronics, Vol. 25, No. 2, pp310-321.

[15]. Bonfa, V.A., Menegaz, P.J.M., Vieira, J.L.F. & Simonetti, D.S.L., (2002) “Multiple alternatives of regenerative snubber applied to SEPIC and Cuk converters”, IEEE 28th Annual Conference of the Industrial Electronics Society, Vol. 1, pp123-128.

[16]. Fang, C.C. & Redl, R., (2017) “Subharmonic Instability Limits for the Peak-Current-Controlled Boost, Buck–Boost, Flyback, and SEPIC Converters with Closed Voltage Feedback Loop”, IEEE Transactions on Power Electronics, Vol. 32, No. 5, pp4048-4055.

[17]. Lee, S.W. & Do, H.L., (2017) “Zero-Ripple Input-Current High-Step-Up Boost–SEPIC DC–DC Converter with Reduced Switch-Voltage Stress”, IEEE Transactions on Power Electronics, Vol. 32, No. 8, pp6170-6177.

[18]. Park, K.B., Moon, G.W. & Youn, M.J., (2010) “Nonisolated High Step-up Boost Converter Integrated with SEPIC Converter”, IEEE Transactions on Power Electronics, Vol. 25, No. 9, pp2266-2275.

[19]. Costa, P.J.S., Font, C.H.I. & Lazzarin, T.B., (2017) “A Family of Single-Phase Voltage-Doubler High-Power-Factor SEPIC Rectifiers Operating in DCM”, IEEE Transactions on Power Electronics, Vol. 32, No. 6, pp4279-4290.

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