International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 4, December 2017, pp. 1585~1594
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i4.pp1585-1594

Analysis and Evaluation of Performance Parameters of Modified Single Ended Primary Inductance Converter

Hemalatha J. N.[1], Hariprasad S. A.[2], Anitha G. S.[3]
[1,3] R V college of Engineering Bengaluru, India
[2]Jain University, India

Article Info

Article history:

Received Sep 11, 2017
Revised Nov 16, 2017
Accepted Dec 1, 2017

Keyword:

Multiple input converter
Passive lossless snubber
Pulse Width Modulator
Zero Current Switching
Zero Voltage Switching

ABSTRACT

The objective of this paper is to propose a modified Single Ended Primary Inductance converter topology with passive lossless snubber cell to achieve Zero Voltage Switching (ZVS) of the device near turn off and Zero Current Switching (ZCS) near turn on. By using the snubber cell effectively with the converter reduces the switching stress by restricting the large variations in voltage and current. The detailed analysis of the circuit with relevant waveforms of the circuit is described. The circuit is designed for a load of 100W at 12V output from an input source ranging between 20-30V. The circuit is modelled in MATLAB Simulink platform and the parameters are compared with conventional circuit. From the results it is shown that the proposed circuit operates at a lesser voltage stress and at higher efficiency than conventional one.

Corresponding Author:

Anitha G. S.,
R.V. College of Engineering Bengaluru, India.
Email: anithags@rvce.edu.in

1. INTRODUCTION

Power Electronic interface in renewable power conversion system plays a vital role in maintaining constant output voltage as the input renewable sources like solar, wind etc are highly stochastic in nature. Conventionally this system uses pulse width modulated DC-DC converter as it can handle higher power capability and the control strategy is simple and easy to implement. Any power electronic device has a definite turn on and turn off time, these switching times are the prime source for the switching losses and EMI noises in converter circuit. It is therefore very important to reduce these switching losses in the converter to maximize the efficiency. To achieve faster response in PWM converters the switching frequency of the system is to be increased but with increase frequency, the switching losses, electromagnetic interference also increases that leads to decrease in efficiency. The main causes are the non ideal factors of a circuit like internal resistances of the various components used that result in more conduction losses and for the switching losses and EMI due to large dv/dt and di/dt transient that occurs during switching operations [1]-[2].

To improve the performance of the circuit and to reduce the effects of non ideal factors many soft-switching technologies have been proposed in the literature [3]-[10]. Some of the topologies deals with active snubber, as introduced in [3]-[5], can give very good performance with reduction in losses by using auxiliary device. But, requirement of an auxiliary device increases difficulty in the design of both power circuit and control circuit as it is very challenging to manage the control signals of the two devices specifically during transients. Using active snubber increases the cost and reduce the reliability and stability. In the other class of topologies [6]-[10] involves RCD snubber requires resistors, capacitors and diodes. Though they are simple to design and less expensive they do not give better performance with increase in conduction losses so the efficiency of the circuit reduces. Resonant converter topologies give zero voltage and zero current switching so switching losses are reduced but the conduction losses are not reduced also the design of filters is complicated.

Compared to these three class of topologies, a passive lossless snubber topologies which do not require any active switching device or energy dissipating components, can effectively reduce the switching losses and EMI noise [11]–[12]. The main merits of passive lossless snubber circuit converters are simple in design, low cost, high efficiency and high degree reliability due to less voltage stress across the device.

Various converter topologies for different applications proposed in the literature [13]-[18]. Among all the non-isolated dc-dc converters SEPIC topology proved to be the best one with refence to the efficiency, ripple in voltage, current. This paper aims at the detailed analysis and evaluation of performance parameters of Single Ended Primary Inductance Converter modified with passive lossless snubber cell. The circuit is designed and simulated for input specification of 20 -30V, 100W and output of 12V, 100W with switching frequency of 150KHz and efficiency of greater than 85%.

2. PASSIVE LOSSLESS SOFT SWITCHING CONVERTERS

To synthesise a passive lossless soft switching converter requires a thorough understanding of topological and electrical properties of the basic PWM converter components, snubber components and their characteristics. Inclusion of snubber elements should not only reduce di/dt and dv/dt of device, but also helps in recovering energy and maintain a reasonable voltage stress across the device. The energy transfer functions are obtained during the switching interval which is very small. The duration of switching mainly depends on switching peed, characteristics of the converters and snubber elements size. After the switching duration, the converter operates in the normal PWM mode. The analysis of the converter is done with an assumption that the snubber cell does not change the basic PWM operation of the converter except for a small switching transient time. The important function of turn on snubber is to reduce the rise time of the device. Generally turn on snubber is implemented with inductor. The role of turn off snubber is to reduce the device voltage rise time. This is achieved by using capacitors. To have an efficient design of converter the energy stored in these elements has to recover during each switching. A detailed procedure for the synthesis of modified converter topologies using passive lossless snubber cells is discussed in [11]. In this paper analysis and performance evaluation of Single Ended Primary Inductance Converter with and without passive lossless snubber is carried out.

3. ANALYSIS OF PASSIVE LOSSLESS SEPIC CONVERTER

Figure 1 shows the circuit schematic of proposed converter. Figure 2 shows the equivalent circuit diagrams under different operating modes. Figure 3 gives the waveforms across the device, load, capacitor, and inductor.

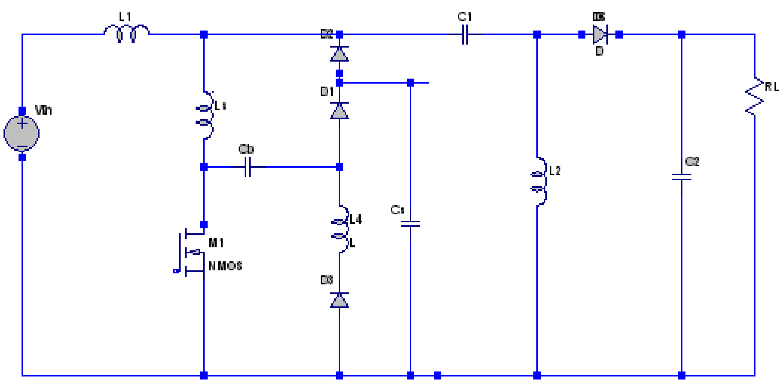

Figure 1. Circuit schematic of modified SEPIC converter

The analysis of the converter is done in six different operating modes. Figure 2a to Figure 2h shows the equivalent circuits under each operating mode for The complete analysis of converter.

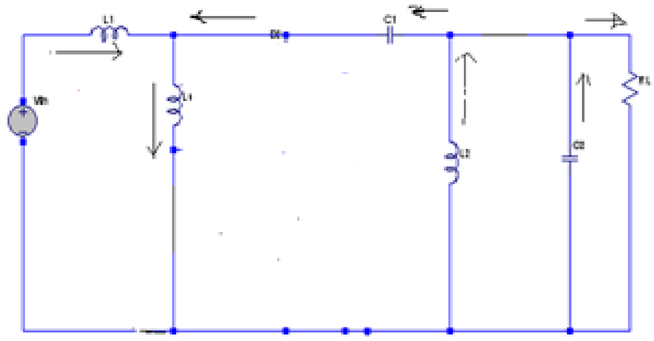

Figure 2a. Mode 1 equivalent circuit

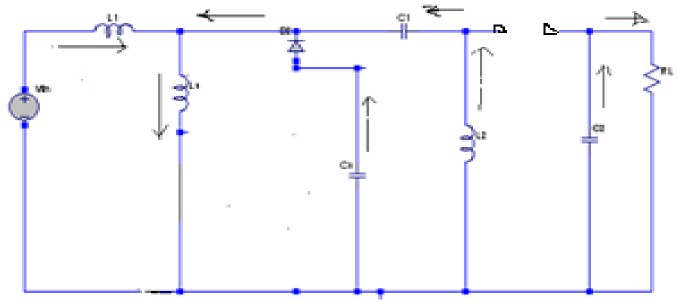

Figure 2b. Mode 2 equivalent circuit

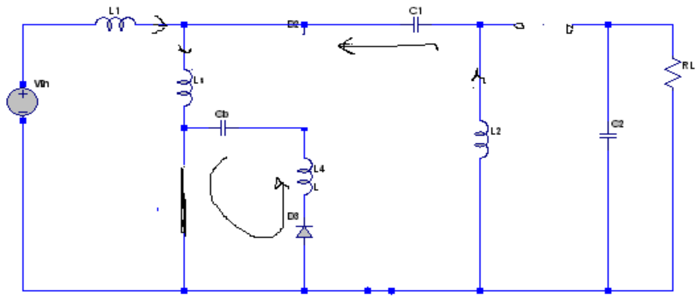

Figure 2c. Mode 3 equivalent circuit

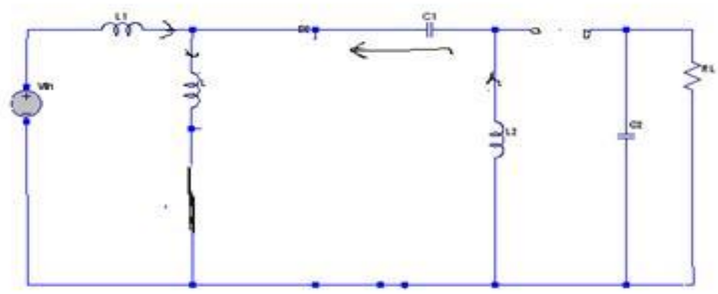

Figure 2d. Mode 4 equivalent

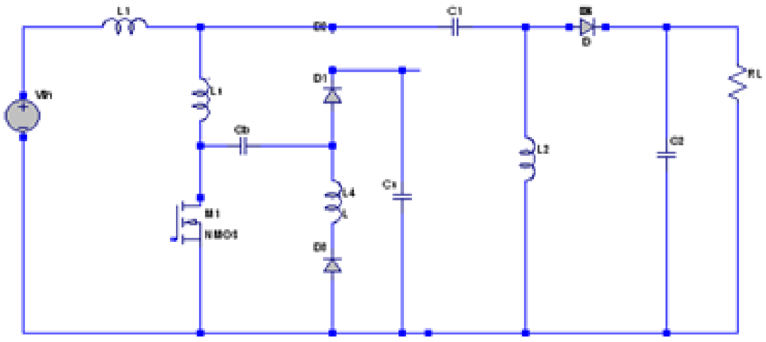

Figure 2e. Mode 5 equivalent

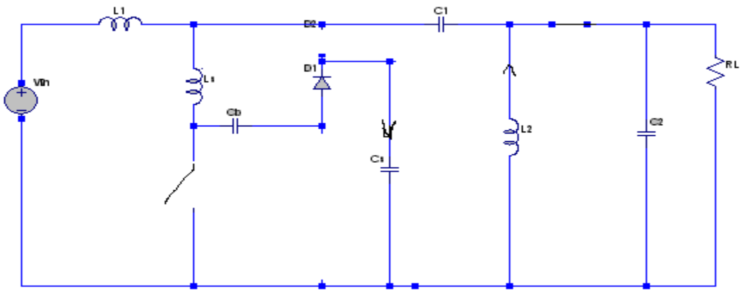

Figure 2f. Mode 5 equivalent circuit

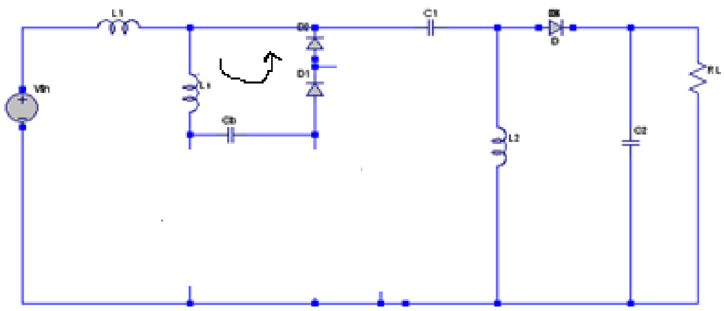

Figure 2g. Mode 6 equivalent circuit

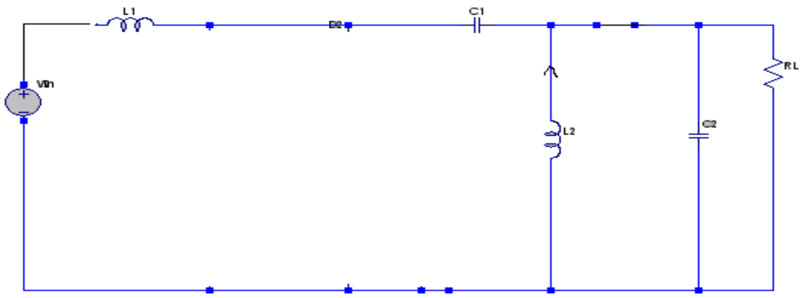

Figure 2h. Mode 7 equivalent circuit

3.1. Switching Waveforms

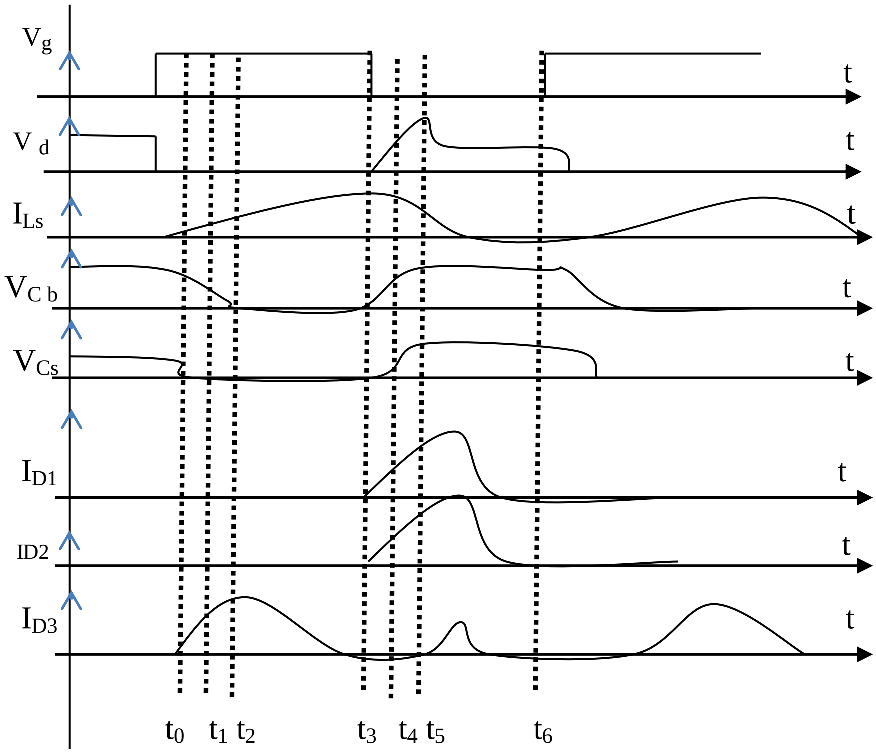

Figure 3. waveforms of voltage across gate, switch, snubber capacitor, buffer capacitor, diode currents

Mode1:

When the switch is turned on inductor current in Ls slowly ramps up providing zero current turn on for the switch. But due to reverse recovery process of the freewheeling diode it continue to be in on state. The equivalent circuit is as shown in Figure2a.

The voltage across inductor Ls is given by $V_{LS} = L_S \frac{diLs}{dt}$ (1)

In integral form $V_{LS} = Ls \frac{Is}{t1}$ (2)

$$\therefore t_1 = \frac{Ls\ Is}{V\ Ls} \quad (3)$$

Mode 2:

The diode turns off. The snubber Capacitor Cs and snubber inductor L_S forms a resonance circuit, capacitor discharges, so its energy gets transferred to L_S The equivalent circuit is as shown in Figure 2b). The current through the inductor is given by

$$I_{LS}(t) = I_s + \frac{Vcs}{Zn} \text{ Sin } (Wn\ (t - t_1)) \quad (4)$$

Where Wn is resonant frequency = $\frac{1}{\sqrt{LsCs}}$

Zn is resonant impedance = $\sqrt{\frac{Ls}{Cs}}$

The capacitor voltage is given by

$$VCs = VCs\ (t2)\ \text{Cos}\ (Wn\ (t-t_1)) \quad (5)$$

By the end of this mode capacitor discharges completely, diode D_2 turns off.
Mode 3:

In this mode the capacitor C_b discharges to L_{s2} through the switch, C_b energy gets transferred to L_s, after completion of discharge the diode D_3 gets turned off. The equivalent circuit is as shown in Fig 2c. The inductor current though L_{s2} is given by

$$I_{Ls2} = \frac{Vcb}{Zn2} \text{Sin} (Wn (t-t_3)) \quad (6)$$

Z_{n2} is the resonance impedance $= \sqrt{\frac{Ls}{Cb}}$

Mode 4:

The time duration t_1- t_3 is a small resonant interval where energy exchange happens. In mode 4 the circuit operates in normal PWM mode in which the input inductor stores energy and the capacitor C_1 discharges the inductor L_2. The load is supplied from the output capacitor. The equivalent circuit is as shown in Figure 2d

Mode 5:

The switch is turned off when the inductor energy L_{S2} fully gets transferred to Cs achieving Zero voltage turn off across the switch. The equivalent circuit is as shown in Figure 2e.

Mode 6:

The switch is turned off the inductor current falls slowly charging Cs and C_b forming a resonance. The equivalent circuit is as shown in Figure 2f.

The inductor current is given by $I_{Ls1}(t) = IL_m - \frac{VLs}{Zn3} \text{Sin} (Wn(t-t5))$ (7)

The resonant impedance $Z_{n3} = \frac{Ls}{Ceq}$ $\quad$ $Ceq = \frac{Cs+Cb}{CsCb}$

$$Wn = \frac{1}{\sqrt{LsCeq}} = \sqrt{\frac{CsCb}{Ls(Cs+Cb)}}$$

Mode7:

In this mode Cs continue to charge through D_1 and D_2. After it fully charges the inductor energy completely gets transferred to C_b. The equivalent circuit is as shown in Figure 2g.
Inductor current is given by

$$I_{Ls} (t)= I_{Ls}(t6) - \frac{VLs}{Zn4} \text{Sin} (Wn(t-t6)) \quad (8)$$

$$Z_{n4} = \sqrt{\frac{Ls}{Cb}} \qquad Wn = \frac{1}{\sqrt{LsCb}}$$

In this mode converter operates in normal PWM mode. In input inductor energy is delivered to capacitor C_1 and Inductor L_2 is getting charged. Output capacitor maintains the voltage across the load.

3.2. Simulation validation of Proposed Converter

The circuit is designed for the specifications of 10V,30W output and input voltage of 30V. The design of the main PWM components of the converter is carried out in conventional way to meet the desired requirements. The design of snubber components is of more interest, the key points are the resonant frequency must be higher than the switching frequency. The buffer capacitance is chosen such that it is at-least 30 times more than snubber capacitance considering the reverse recovery energy. Large snubber inductor is selected to reduce the reverse recovery loss.

Table 1. List of components

Component	Value
Input Source	30V
Inductor L1	2mH
Inductor L2	0.02mH
Capacitor C1	80uF
Capacitor C2	66uF
Switching frequency	150KHz
Snubber Inductance	2uH
Snubber Capacitance Cs	3uf
Buffer Capacitance C b	100uf
Duty Cycle	30%

Table 1 gives the list of components used in the circuit after the design to study the performance of the circuit. Figure 4 shows the Simulink model of the proposed converter circuit. It is simulated to evaluate the performance parameters. Figure 5 shows the waveforms of diode currents, gate voltage and switch voltage. Figure 6 shows the waveforms of inductor currents, capacitors voltage and output voltage.

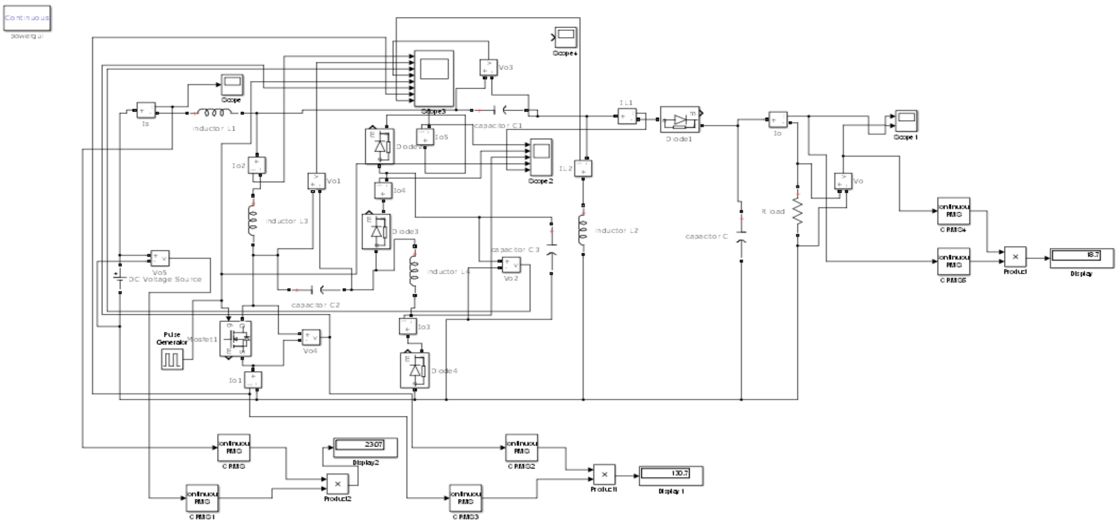

Figure 4. Simulink diagram of proposed converter.

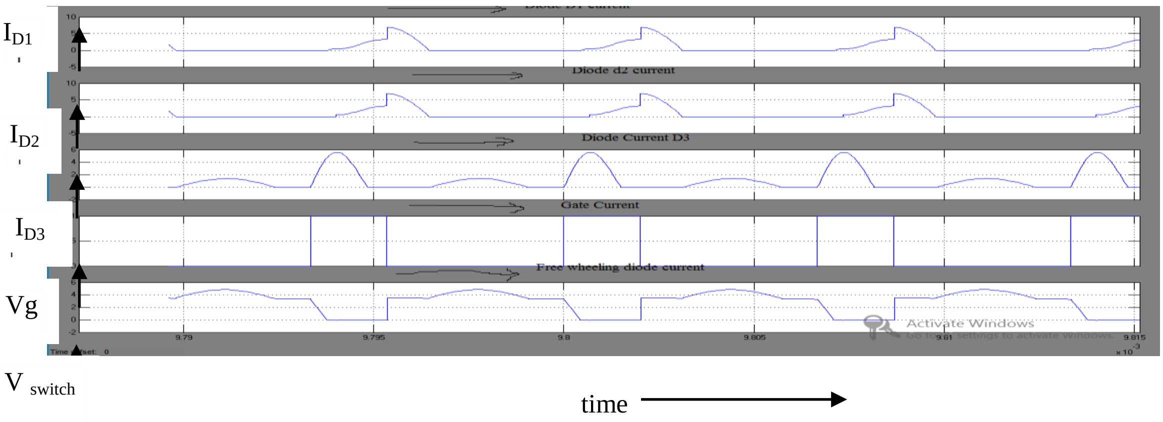

Figure 5. Waveforms across diode currents, gate voltage, switch voltage

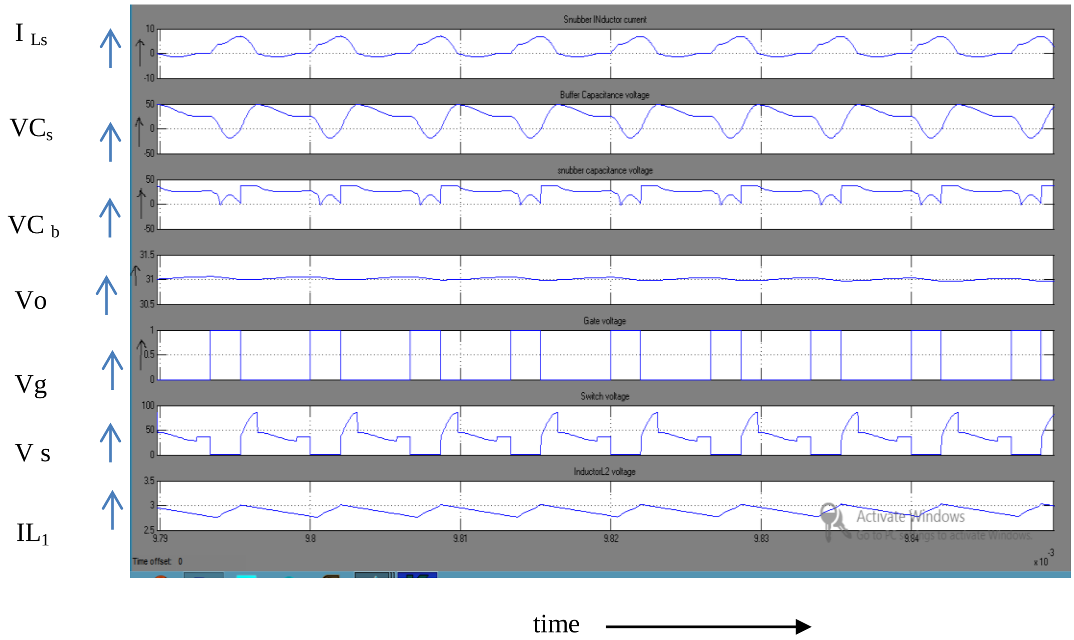

Figure 6. waveforms of voltage, currents

Table 2. Performance parameters of the proposed converter and conventional converter

Topology	Input current ripple in A	Output current ripple A	Output voltage ripple in A	Switch stress in W	Input Power	Output Power	Efficiency
Proposed	0.71-0.689=0.021	3.185-3.144=0.041	6.37-6.28=0.09	125	23.07	20.7	89.6
Conventional	2.47-2.44=0.03	6-5.85=0.15	12-11.82=0.18	165	77	66	85

Table 2. gives the comparative study of parameters of the proposed converter namely the ripple voltage, ripple current, efficiency and stress across the device with that of the normal SEPIC.

4. CONCLUSION

This paper proposes a modified SEPIC converter which includes a passive loss less snubber cell which gives zero current switching during turn on.. During switching, the large dv/ dt and large di/dt are controlled that reduces the switch stress and that results in the improvement in the efficiency. The circuit is analysed in detail with the design considerations. The proposed converter is simulated in MATLAB Simulink platform to study the performance. From the analysis it is observed that the proposed converter gives better performance than the conventional converter with respect to the current ripple about 2.1%, voltage ripple about 4.1%, efficiency of 89.6%and the switch stress about 23watts.. As it provides good performance the proposed converter is most suitable topology in renewable distributed generation systems.

ACKNOWLEDGMENT

I thank my guide Dr S A Hariprasad and co-guide Dr G S Anitha for their valuable guidance, suggestions in preparation of this paper. I thank my college for giving me facilities to carry out the work.

REFERENCES

[1] Fang Lin Luo , Hong Ye, “Advanced DC/AC converters- Applications to Renewable Energy”, CRC Press, 2013, ISBN 9781466511354

[2] Ned Mohan, Tore M. Undeland, William P. Robbins, “Power Electronics Converters, Applications, and Design”, 3rdEdition. Wiley India Pvt Ltd, 2011. ISBN: 978-0-471-22693-2

[3] A. Elasser and D. A. Torry , "Soft switching active snubbers for dc/dc converters," IEEE Trans. Power Electron., vol. 11, pp. 710–722, Sept.1996.
[4] G. Hua and F. C. Lee, "Soft-switching techniques in PWM converters," IEEE Trans. Ind. Electron., vol. 42, pp. 595–603, Dec. 1995.
[5] R. L. Lin and F. C. Lee, "Novel zero-current-switching-zero-voltage switching converters," in Proc. PESC'96, 1996, pp. 438–442.
[6] R. Streit and D. Tollik, "High efficiency telecom rectifier using a novel soft-switched boost-based input current shaper," in Proc. INTELEC'91,1991, pp. 720–726.
[7] S. J. Finney, B. W. Williams, and T. C. Green, "The RCD snubber revisited," in Conf. Rec. IEEE-IAS Annu. Meeting, 1993, pp. 1267–1273.
[8] G. A. Karvelis and S. N. Manias, "Fixed-frequency buck-boost zero voltage-switched quasi resonant converter," Proc. IEE—Elect. Power Application, vol. 142, no. 5, pp. 289–296, Sept. 1995.
[9] Souvik Chattopadhyay, Santosh Baratam, Hariom Agrawal, "A New Family of Active Clamp PWM DC-DC Converters with ZVS for Main Switch and ZCS for Auxiliary Switch", 978-1-4244-8085-2/11/$26.00 ©2011 IEEE
[10] Fabio Ongaro, Stefano Saggini ZVS Isolated Active Clamp SEPIC Converter for High Power LED applications", 978-1-4577-1216-6/12/$26.00 ©2012 IEEE
[11] K. Mark Smith Jr. and K. M. Smedley "Properties and Synthesis of Passive, Lossless Soft-Switching. PWM Converters", 1st International Congress In Israel on Energy Power & Motion Control, 1997 (EPMC '97).
[12] Ching-Jung Tseng and Chern-Lin Chen, "A Passive Lossless Snubber Cell for Non isolated PWM DC/DC Converters", IEEE Transactions On Industrial Electronics, VOL. 45, NO. 4, AUGUST 1998 .
[13] Bor-Ren Lin, Senior Member, IEEE, Po-Li Chen, and Jyun-Ji Chen," Interleaved SEPIC Converter with Low Switching Loss", TENCON 2010, 978-1-4244-6890-4/10/$26.00 ©2010 IEEE.
[14] Souvik Chattopadhyay, Santosh Baratam, Hariom Agrawal, "A New Family of Active Clamp PWM DC-DC Converters with ZVS for Main Switch and ZCS for Auxiliary Switch", 978-1-4244-8085-2/11/$26.00 ©2011 IEEE
[15] Fabio Ongaro, Stefano Saggini ZVS Isolated Active Clamp SEPIC Converter for High Power LED applications", 978-1-4577-1216-6/12/$26.00 ©2012 IEEE
[16] C.-L. Shen, Y .-E. Wu and M.-H. Chen, "A Modified SEPIC Converter with Soft-Switching Feature for Power Factor Correction", *978-1-4244-1706-3/08/$25.00 ©2008 IEEE*
[17] Tianwen Zhan, Yingchao Zhang, Wusong Wen, Ruiwei Zhang, Zhong He," A novel passive lossless snubber for current-fed half-bridge isolated dc/dc converter", Power Electronics and Motion Control Conference (IPEMC-ECCE Asia), 2016 IEEE 8th International.
[18] Minjae Kim; Daeki Yang; Sewan Choi, " A fully soft-switched multiphase DC-DC converter with reduced switch count for high power application", 2014 International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA).

BIBILOGRAPHY OF AUTHORS

Hemalatha J N, born on 21st July 1975, received B.E degree in Electrical Engineering in 1997and M.E (Power Electronics) in 2001 from Bangalore University. She is currently an Assistant Professor in the Department of Electrical and Electronics at R.V. College Of Engineering . Her research interests are Power Electronic applications in Renewable energy resources and Education. Address : Assistant Professor, Department of EEE, R.V. College of Engineering, 8th mile Mysore Road, Bengaluru -560059. Karnataka, India
E-mail: hemalathajn@rvce.edu.com

Dr. Hariprasad S A Obtained B.E degree in the year 1991 and M.E in the year 2000,completed Ph.D. degree in the year 2011 and two additional highest degrees, Doctor of science degrees in the year 2013 and 2014 for the post-doctoral research work on communication and embedded systems. Currently working as Director, School of Engineering technology ,Jain University, Bengaluru. Published 60 papers in International and National Journals / conferences and a text book on Advanced microprocessor. Guided 34 PG projects, 40 UG projects and currently guiding 08 P h. D students. Held key posts, like Director for Cognitive science, RVCE, Vice-principal, BMSIT, Pro-vice- Chancellor-DayanandaSagar University, Academic mentor for DSCE and DSATM. Established industry supported labs. Served as visiting professor to various reputed colleges in Bangalore. Delivered Expert talk in conferences and workshops in the area of embedded systems and microwave engineering domains.
E-mail:harivat2002@yahoo.co.in

Dr G S Anitha, born on 29th Sept 1960, received BE degree in Electrical Engineering, M.E from Bangalore University and PhD in 2010 from Avinashilingam Deemed University. She is currently an Associate Professor in the Department of Electrical & Electronics Engineering at R. V. College of Engineeing. Her research interest in in the area of power systems, renewable energy, high voltage, electrical machines. Etc.,
E-mail: gsanitha@rvce.edu.in