PV Fed Sepic Triple-Lift Converter System - A Comparative Study

T. Ezhilan, J. Ravikumar, B. Baskaran, S. Subramanian

Abstract: Power converter design based on voltage-lifting (VL) techniques avoid taking a too high value of operating duty for producing large voltage conversion ratio. This study is aimed in determining the voltage boosting ability of a soft-switched single ended primary inductor converter (SSSEPIC) integrated with triple-lift converter system (TLCS). Simulation of SSSEPIC-TLCS is performed in open loop and with source disturbance by developing a Matlab Simulink model. The converter performance is studied with regard to voltage gain, ripple content present in output voltage and power output. Furthermore, the SSSEPIC-TLCS is compared with the results of elementary SEPIC, self-lift, double-lift and re-lift converter reported in literature so as to find a system with high power output and low output voltage ripple. A T-filter is connected at the output to minimize ripple content. Comparative results reveal that combination of SEPIC with re-lift system produces higher output than other VL methods and therefore it is a good substitute for the existing step-up converters. Moreover, the results suggest that there has only been a marginal difference in voltage gain and power output between triple-lift and double-lift converter system.

Index Terms: Soft-switched single ended primary inductor converter (SSSEPIC), Triple-lift converter system (TLCS), Voltage lifting (VL) methods, Matlab Simulink.

1 INTRODUCTION

In order to get steep voltage from a classical boost converter, it has to be operated at an extreme duty cycle value [1]. In contrast, the converter efficiency will get lessened due to power losses at high conduction duty [2]. In addition, electromagnetic interference (EMI) and reverse recovery effect occur at high operating duty. As a consequence, traditional boost converters cannot be employed for applications that need high voltage gain [3], [4]. The literature concerning implementation of DC-DC converters for high voltage applications is very broad and umpteen power conversion circuits can be found in it to get rid of the aforesaid limitations in a boost converter. Some quintessential methods include: Converters employing magnetic/electric field storage elements, converters with and without transformers, voltage multiplier (VM) modules integrated with a traditional boost converter and by cascading the converters [5], [6], [7], [8]. In spite of the fact that these methods can be used to extend the voltage operating range, the shortcomings such as switch turn ON/OFF losses in a magnetic converter switching surges in a transformer and circuit complexity in cascaded approach restrict their usage in high voltage applications [9].

- *T. Ezhilan, Research scholar, Department of Electrical Engineering, Annamalai University, Chidambaram, Tamilnadu, India.*
  Email: ezhilanelectrical@gmail.com
- *J. Ravikumar, Assistant Professor, Department of Electrical Engineering, Annamalai University, Chidambaram, Tamilnadu, India. E-mail: sriram1505@gmail.com*
- *B. Baskaran, Professor, Department of Electrical Engineering, Annamalai University, Chidambaram, Tamilnadu, India.*
  E-mail: baskarancdm@gmail.com
- *S. Subramanian, Professor and Head, Department of Electrical Engineering, Annamalai University, Chidambaram, Tamilnadu, India. E-mail: profdrmani@gmail.com*

Design of switching regulators based on VL techniques has gained prominence in recent years. F.L.Luo's pioneering research work in power converter design has led to the development of a series of positive/negative DC output voltage regulators which can produce high voltage and efficiency simultaneously without taking a too high value of duty cycle [8], [9], [10], [11]. An intelligible survey of most recent VL methods is provided in [12]. In a nutshell the unique features, strengths and shortcomings of various VL methods have been summarized with their applications. VL design is applied to a transformer-less converter structure and new power conversion topologies that can give wide voltage ratio have been constructed from it for use in applications that need high voltage in DC level [8]. Step-up converters with less number of switches have been developed by applying VL technique into the SEPIC prototype for industrial applications and to design electronic circuits [9]. Lossless switching methods in which switching devices turn ON/OFF at zero voltage/current are used in the design of converter especially at high operating frequencies for improving power conversion efficiency and also to minimize the conduction losses [4]. SEPIC converter topology is favoured in the design of switching power supplies owing to its high gain flexibility. Besides, having minimum ripple content at its input, SEPIC topology does not suffer from output voltage polarity inversion [13]. A novel soft-switched SEPIC with an efficiency of 94.8% is presented in which VM techniques, coupled/auxiliary inductor are utilized for lowering switch turn ON/OFF losses, voltage stresses induced across active/passive switching devices and also to completely eliminate the pulsating input DC current [4]. Authors in [14] have used the SEPIC topology presented by H.L.Do and experimentally investigated the voltage profile of self-lift, re-lift and elementary SEPIC converter system. Simulation and hardware results reveal that SEPIC combined with re-lift system produces high power output. The simulation results of open loop controlled SEPIC double-lift converter are reported in [15]. Inspired by the encouraging results provided in [4], [8], [9], [10], [11] the aim of the paper is to examine the performance of SSSEPIC-TLCS in open loop and with source disturbance. Results reported in [14] and [15] are compared with SEPIC triple-lift system to identify a system with high power output. The organization of the

paper is as follows: Section-1 briefly discusses the recent works reported in literature. The operation of ZVS resonant SEPIC converter conceived by H.L.Do is described in section-2. Comparative simulation results of various open loop controlled SEPIC converter systems obtained from Matlab Simulink are presented in Section-3. The concluding remarks are given in section-4.

2 ZVS RESONANT SEPIC CONVERTER [4]

(Adapted from Hyun-Lark Do IEEE Trans. on Power Electronics, vol. 27, no. 6, June 2012) Several topological variations of SEPIC exist in the literature. Hyun-Lark Do has proposed a ripple free circuit configuration of SEPIC using soft-switching scheme and the converter structure is presented in Fig. 1(b). Fig. 1(a) shows a simple classical SEPIC converter with a resonant inductor L_r, clamp circuit auxiliary switch S_a along with clamp capacitor. Fig. 1(c) represents the equivalent circuit model of SSSEPIC in which L_c is reconfigured as magnetic inductor L_m along with an ideal transformer which has a turns ratio of 1:n. The switches D_a and D_m coupled across auxiliary switch S_a and main switch S_m are utilized for freewheeling purposes. The internal capacitances of switches S_a and S_m which operate asymmetrically are represented by C_a and C_m respectively. If capacitors C_1, C_o and C_c are assumed to be fairly large, voltage ripples can be ignored. Smoothing inductor L_1 helps in decreasing ripple content in the input.

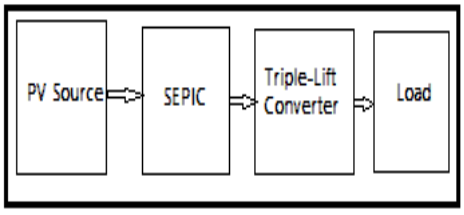


Fig. 2 *Block diagram of SSSEPIC-TLCS*

3.1 Open loop SEPIC converter with triple-lift system

The Matlab Simulink model developed for SSSEPIC-TLCS is given in Fig. 3(a). DC output measured using solar system which is shown in Fig. 3(b) is stepped up by using SSSEPIC and it is further boosted with the help of TLCS. The triple-lift converter circuit is presented in Fig. 3(c). The operation is as follows: When M_1 is triggered two current loops are established. Loop I: From V_{in} through D-C_2-D_1-D_4 and M_1. Loop II: From V_{in} through D-D_3-C_3-D_4 and M_1 thereby charging both C_2 and C_3 to full source voltage V_{in}. When M_1 is turned off, all appropriate diodes are reverse biased and gets turned off. Therefore, V_{in} gets coupled through L-C_2-L_1-C_3-L_2 to C_1 or D_2-R_L and voltage gets lifted to three times [V_{in}+ C_2+ C_3 = C_1 ($3V_c$)]. Input voltage to the converter is shown in Fig. 3(d) and its value is 15 volts. The output voltage and its ripple, current and power waveforms across R-load of SSSEPIC-TLCS are shown in Fig. 3(e), 3(f), 3(g) and 3(h) respectively. Their values are found to be 72V, 0.04V, 0.64A and 47W. The parameters used for simulation are listed in Table 1.

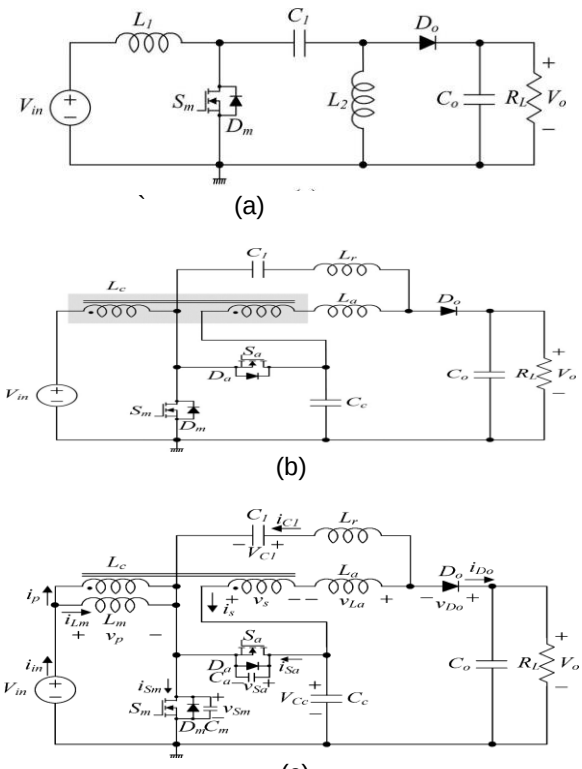
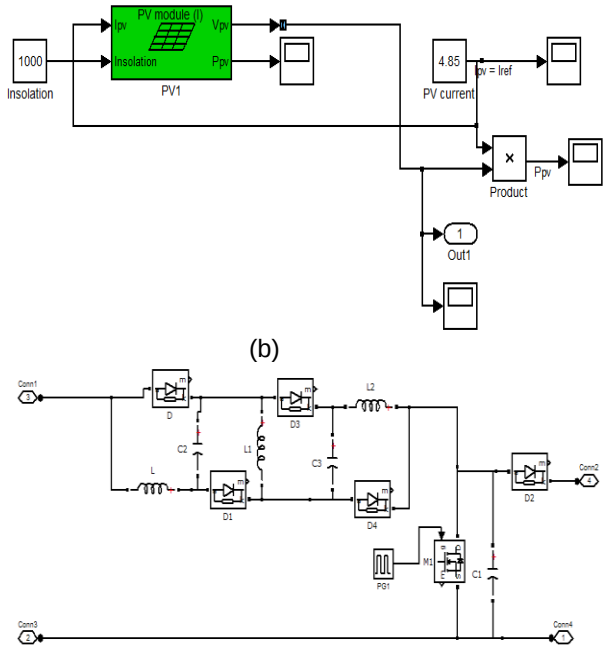
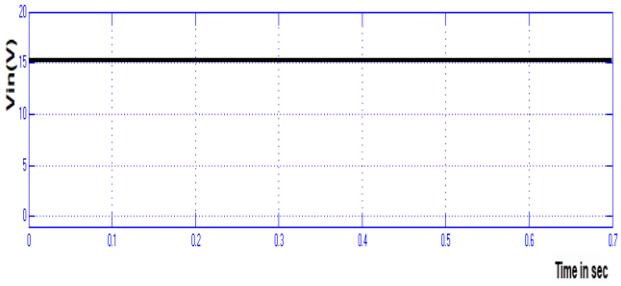


Fig.1 *(a) Classical SEPIC (b) SSSEPIC structure (c) Ripple-free equivalent circuit model of SSSEPIC*

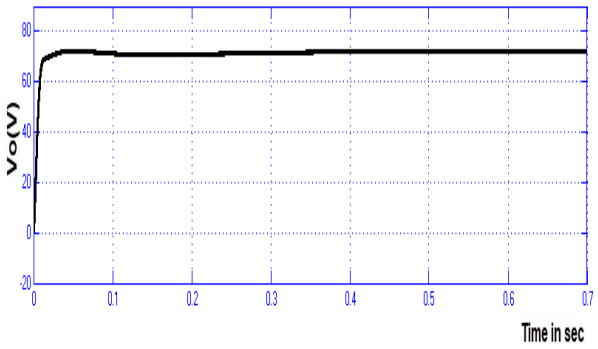
3 SIMULATION RESULTS

The voltage enhancing ability of open loop controlled SSSEPIC-TLCS is investigated in this work by developing a Matlab Simulink model. The schematic diagram of open loop SSSEPIC-TLCS is given in Fig. 2.

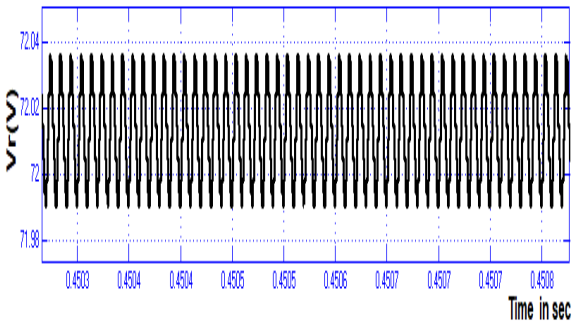




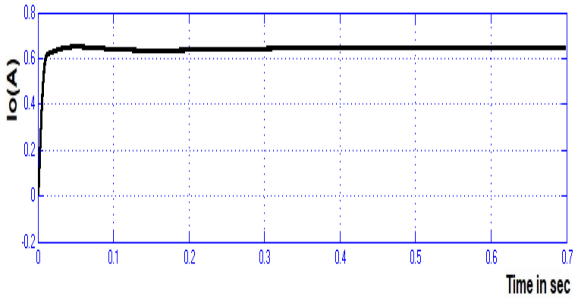
(a)



(e)



(f)



(g)

(h)

Fig. 3 SSSEPIC-TLCS: (a) Matlab Simulink model (b) measurement of power in solar system (c) circuit of triple-lift converter (d) output voltage across solar source (e) output voltage across R-load (f) output voltage ripple (g) output current through R-load (h) output power waveform

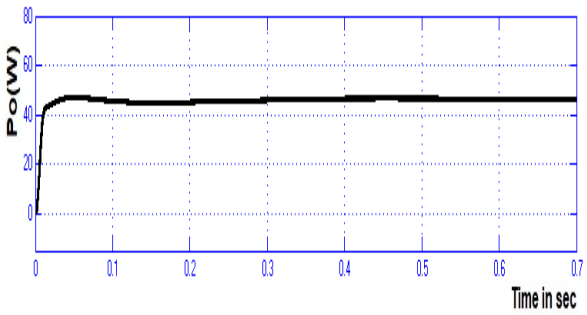


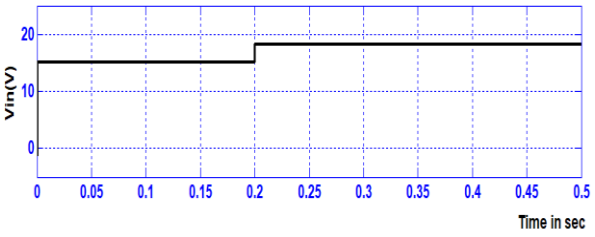
TABLE 1

PARAMETER VALUES TAKEN FOR SIMULATION STUDY

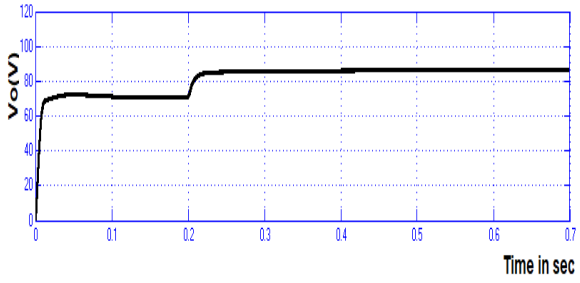
Parameters	Simulation
L_1	35 µH
C_1	6.6 µF
C_2	100 µF
R_L	100 Ohm
V_{in}	15-18 V

3.2 Open loop SSSEPIC-TLCS with source disturbance

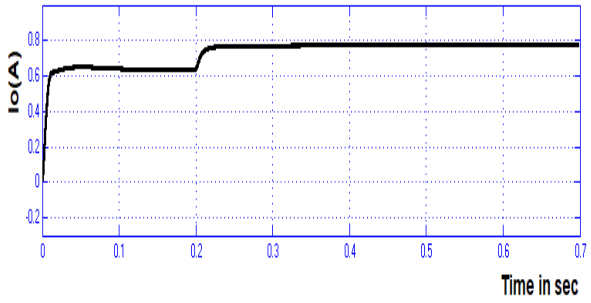
Voltage across photo voltaic (PV) source of SSSEPIC-TLCS with disturbance is shown in Fig. 4(a) and its value is 15 to 18V. The output voltage, current and power waveforms across R-load of TLCS are shown in Fig. 4(b), 4(c) and 4(d) respectively. Their values are found to be 85V, 0.79A and 65W. Table 2 summarizes the performance of open loop controlled classical SEPIC cascaded with self-lift, re-lift, double-lift and triple-lift converter.



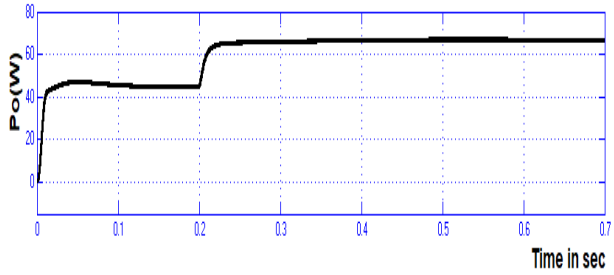
(a)



(b)



(c)



(d)

Fig. 4 *SSSEPIC-TLCS with source disturbance: (a) output voltage across solar source (b) output voltage across R-load (c) output current through R-load (d) output power waveform*

TABLE 2
COMPARISON OF OUTPUT VOLTAGE, OUTPUT CURRENT, OUTPUT POWER AND VOLTAGE RIPPLE

SEPIC Converter	V_{in} (V)	V_o (V)	I_o (A)	P_o (W)	Ripple Voltage (V)
Elementary [14]	15	60	0.56	35	0.03
Self-Lift [14]	15	75	0.72	54	0.02
Re-Lift [14]	15	80	0.75	60	0.02
Double-Lift [15]	15	68	0.60	41	0.05
Triple-Lift	15	72	0.64	47	0.04

4 CONCLUSION

This paper has studied the applicability of SSSEPIC-TLCS for applications that need a high voltage in DC level. The open loop response of triple-lift converter is examined by developing a model in Matlab Simulink. Simulation results of SSSEPIC-TLCS is compared with elementary SEPIC, self-lift, re-lift and double-lift converter system in order to find a system with high output power. Comparative results confirm the superior performance of SEPIC re-lift converter over other VL techniques and therefore it can be a good replacement for the existing step-up converters. Simulation results also indicate that there is a negligible difference in voltage gain and power output between triple-lift and double-lift converter.

REFERENCES

[1] Sanghyuk Lee, Pyosoo Kim and Sewan Choi, “High step-up soft-switched converters using voltage multiplier cells”, IEEE Trans. Power Electron., vol. 28, no. 7, pp. 3379–87, July 2013.

[2] Yiyang Li and Swamidoss Sathiakumar, “Improved quadratic boost converter based on the voltage lift technique,” 2017 Asia Modelling Symposium, pp. 139–44. DOI 10.1109/AMS.2017.30

[3] Fernando Lessa Tofoli, Denis de Castro Pereira, Wesley Josias de Paula and Demercil de Sousa Oliveira Junior, “Survey on non-isolated high-voltage step-up dc-dc topologies based on the boost converter,” IET Power Electron., vol. 8, iss. 10, pp. 2044–67, 2015.

[4] Hyun-Lark Do, “Soft-switching SEPIC converter with ripple-free input current,” IEEE Trans. Power Electron., vol. 27, no. 6, pp. 2879–87, June 2012.

[5] Yi-Ping Hsieh, Jiann-Fuh Chen, Tsorng-Juu Liang and Lung-Sheng Yang, “Novel high step-up DC-DC converter with coupled-inductor and switched-capacitor techniques,” IEEE Trans. Ind. Electron., vol. 59, no. 2, pp. 998–1007, Feb. 2012.

[6] Miao Zhu, Tao Wang and Fang Lin Luo, “Analysis of voltage-lift-type boost converters,” 7th IEEE Conf. on Ind. Electr. and Appln. (ICIEA), pp. 214–19, Juiy 2012.

[7] Marcos Prudente, Luciano L.Pfitscher, Gustav Emmendoerfer, Eduardo F.Romaneli and Roger Gules, “Voltage multiplier cells applied to non- isolated DC–DC converters,” IEEE Trans. Power Electron., vol. 23, no. 2, pp. 871–87, Mar. 2008.

[8] Y. Jiao, F.L. Luo and B.K. Bose, “Voltage-lift split-inductor-type boost converters,” IET Power Electron., vol. 4, iss. 4, pp. 353–62, April 2011.

[9] M. Zhu and F.L.Luo, “Series SEPIC implementing voltage-lift technique for DC–DC power conversion,” IET Power Electron., vol. 1, no. 1, pp. 109–21, 2008.

[10] F.L.Luo, “Seven self-lift DC-DC converters, voltage lift technique,” IET Proc.-Electr. Power Appln., vol. 148, no. 4, pp. 329–38, July 2001.

[11] F.L.Luo, “Re-lift converter: design, test, simulation and stability analysis,” IET Proc.-Electr. Power Appln., vol. 145, no. 4, pp. 315–24, July 1998.

[12] Mojtaba Forouzesh, Yam P. Siwakoti, Saman A. Gorji, Frede Blaabjerg and Brad Lehman, “Step-Up DC–DC Converters: A Comprehensive Review of Voltage-Boosting Techniques, Topologies, and Applications,” IEEE Trans. Power Electron., vol. 32, no. 12, pp. 9143–78, Dec. 2017.

[13] Giulia Di Capua and Nicola Femia, “A critical investigation of coupled inductors SEPIC design issues,” IEEE Trans. Power Electron., vol. 61, no. 6, pp. 2724–34, June 2014.

[14] T.Ezhilan, J.Ravikumar, B.Baskaran and S.Subramanian, “Fuzzy Logic Controlled SEPIC Re-lift Converter System- A Comparative Study,” International Review of Electrical Engineering (IREE), vol. 14, iss. 5, pp. 302–13, Oct. 2019.

[15] T.Ezhilan, J.Ravikumar, B.Baskaran and S.Subramanian, “Open Loop Response of a SEPIC Double-Lift Converter System,” Journal of Xidian University, vol. 14, iss. 4, pp. 2905–09, April 2020.