Available online at: http://www.ijmtst.com/vol6issue02.html
International Journal for Modern Trends in Science and Technology
ISSN: 2455-3778 :: Volume: 06, Issue No: 02, February 2020

A High Voltage Gain Modified SEPIC Converter

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To Cite this Article
K Sangeetha and Dr. S Senthil Kumar, "A High Voltage Gain Modified SEPIC Converter", *International Journal for Modern Trends in Science and Technology*, Vol. 06, Issue 02, February 2020, pp.-84-89.

Article Info
Received on 20-January-2020, Revised on 09-February-2020, Accepted on 16-February-2020, Published on 22-February-2020.

ABSTRACT

A high voltage gain modified SEPIC converter is proposed in this paper. This presented converter has many advantages i.e., non-inverting output voltage, lower voltage stress, high efficiency, voltage gain is high without any coupled inductor and transformer, continuous input current. Thus, there is no overshoot voltage at turn-off process for switches. By using same gate pulse for two switches, the CCM mode operation can be easily controlled by this converter, so control system is simple and also wide output values is obtained only by modifying the duty cycle. This modified converter has lower components than conventional converter. The operation and design of modified converter are discussed. The performance of proposed SEPIC converter is verified by simulation results.

KEYWORDS: *DC-DC converter, non-isolated converter, non-coupled inductor SEPIC converter,SEPIC converter.*

I. INTRODUCTION

In recent years, high voltage gain is an important research area. Due to increasing in demand of high voltage gain converters for various applications, this converter is proposed. Low power wind turbine, PV, fuel-cells, embedded systems, portable electronic equipment's, uninterruptable power supply (UPS), electric tractions, battery backup for UPS, automobile headlamps, some medical equipment and battery powered equipment are some applications of high gain DC-DC converters [1]. The boost converter is used to step up the output voltage. In order to boost the output voltage, continuous input current is preferred more than discontinuous input current due to some disadvantages [2]. Boost converter (DC-DC) is used widely to step up the output voltage. But the voltage stress is higher in boost converter and also high rated switch is needed that ends in high conduction loss. And also, traditional buck-boost converter is used to step up or step down the voltage level. But it is not suitable for high voltage gain due to its discontinuous input current. Several dc-dc converters such as the flyback converter, single-ended primary-inductance converter (SEPIC), the Cuk converter, forward converter, inverting buck–boost converter has been proposed to obtain the high voltage gain and high efficiency. In flyback converter, efficiency is low due to its high-leakage inductance. The high gain buck-boost converter without transformer has discontinuous input current and negative polarity so it is not suitable.

Mostly isolated DC-DC converters are used for high voltage gain. In isolated DC-DC converters, the overall weight and volume is increased by transformer and also high voltage gain is achieved by transformer turns ratio. During turn off process, the transformer causes voltage spikes due to leakage inductance. The switch voltage is limited by additional clamping circuits and also it recycles the energy. Due to this, cost and complexity is increased with reduced efficiency [3].

Nowadays, a non-isolated dc-dc converter is used widely because of its simplicity, small size, high efficiency, low cost in comparison with other converters [4]. The non-isolated DC-DC boost converter with additional technique i.e., voltage multipliers, cascaded converters, switched capacitor cell and switched inductor cell. These techniques are operated without using any transformer and coupled inductor to achieve high voltage gain but the larger number of components reduces the efficiency with increased complexity [5]-[9].

Due to unique characteristics of SEPIC converter, it is most widely used in power electronics and other applications. In several papers, high voltage gain SEPIC converter is achieved with transformer and coupled inductor but due to its aforementioned drawbacks, it is not widely used [10]-[12]. To improve the performance and efficiency of SEPIC converter, a modified high voltage gain SEPIC converter is presented in this paper. The proposed converter is uncomplicated with lower number of components to have gain compared with other converters. In CCM mode of operation, the converter control is easy and simple by using same gate pulse for two switches. When compared with other non-coupled inductor SEPIC converter, the number of components and voltage stress are less. There is no voltage overshoot during turn off operation results in lower conduction losses. No clamping circuit is needed.

The proposed converter is simple with continuous input current. So, it is suitable for renewable energy applications. The proposed SEPIC DC-DC converter is analyzed and performance are verified by the simulation results for low input voltage and high output voltage.

In section II, modes of operation of the proposed SEPIC converter is presented. In section III, design considerations are discussed. In section IV, the proposed SEPIC converter is compared with other converters. In section V, the experimental results are given, Finally, section VI, conclusion is presented.

II. OPERATING PRINCIPLE OF PROPOSED SEPIC CONVERTER

A modified high voltage gain SEPIC converter is shown in Fig.1. The proposed SEPIC converter consists of one diode D_0, three inductors L1, L2 and L3, two switches S1, S2 and two capacitors CS, C_0. The input source is Vin and output voltage is V_0. The two non-coupled inductor L1, L2 are simultaneously switched and the two inductors are connected in series/parallel at the time of charging mode and discharging mode. Some assumptions are made considered while simplifying the analysis i.e., all the components are ideal, constant capacitor voltage and also number of turns in L1 and L2 are equal.For steady state operation, inductor voltage (V_L) and capacitor currents (Ic) are zero. The proposed SEPIC converter can operate in continuous conduction mode and operating principles of continuous conduction mode has two modes mode 1 and mode 2. In mode 1, both the switches are in ON condition . And in mode 2, both the switches are in OFF condition.

CCM OPERATION

In this operation, there are two operating modes for presented converter. The operation modes are explained in detail as follows.

Mode 1: The diode is blocked and Two switches S1 and S2 are simultaneously turned ON. Then the source energy is transfered to L1, L2, L3. The input voltage is across the parallel connected inductors L1 and L2. The load gets charged from stored energy in the output capacitor. The current flow in mode 1 is given in Fig.2(a). The input inductor voltages are obtained as

$V_{L1} = V_{L2} = V_{in}$ (1)

And the voltage across inductor L3 are obtained as,

$V_{L3} = V_{in} - V_{CS}$

(2)

Mode 2: The diode D_0 are turned ON and S_1 and S_2 are switched OFF. The input voltage and L1, L2 are in series to transferred their energies to the load by D_0 output voltage. The stored energy in the inductor L3 is also transferred to the load by D_0.The input inductor turns ratio and currents are equal.The current flow in mode 2 is given in Fig.2(b).

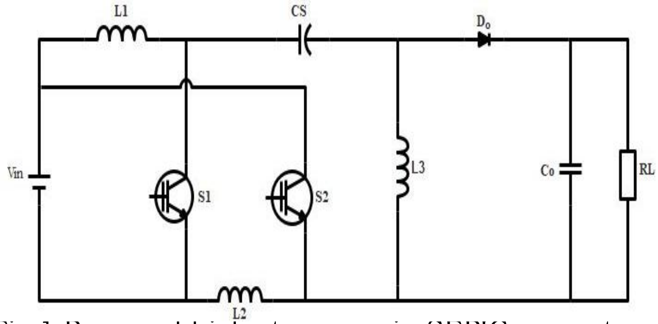

Fig.1 Proposed high step up gain SEPIC converter.

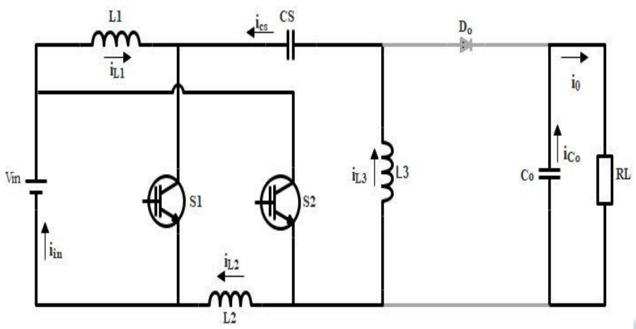

Fig.2(a) Current flow path in Mode 1

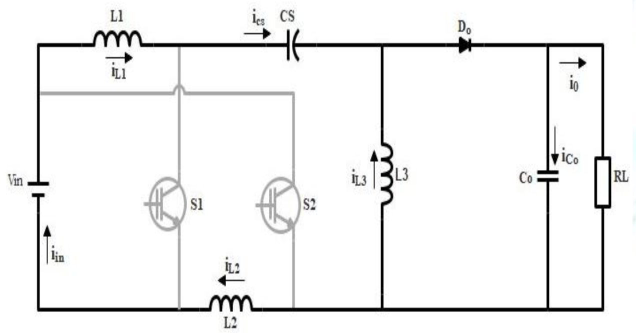

Fig.2(b) Current flow path in Mode 2

Therefore voltage across input inductors are obtained as

$V_{L1} = V_{L2} = \frac{V_{in} - V_O + V_{CS}}{2}$(3)

The voltage across L3 is obtained as

$V_{L3} = -V_{CS}$(4)

By using Kirchhoff's voltage law in path containing Vin, L1, L2, L3, CS gives

$-V_{in} + V_{L1} - V_{CS} - V_{L3} + V_{L2} = 0$(5)

By using the average voltages,

$-V_{in} + 0 - V_{cs} - 0 + 0 = 0$(6)

After solving,

$V_{in} = -V_{CS}$

(7)

For inductor L1and L2

$V_{in} * D + \left(\frac{V_{in} + V_{CS} - V_O}{2}\right)(1 + D) = 0$(8)

$V_{in}(1 + D) + V_{CS}(1 - D) - V_O(1 - D) = 0$(9)

For inductor L3

$(V_{in} - V_{CS})D + V_O(1 - D) = 0$(10) $V_{CS} * D = V_{in} * D + V_O(1 - D)$(11)

The capacitor voltage V_{CS} is given by

$V_{CS} = V_{in} + \frac{V_O(1-D)}{D}$(12)

The voltage gain of modified SEPIC converter is given by the equation

$2D * V_{in} = V_O(1 - D)$

(13)

$\frac{V_O}{V_{in}} = \frac{2D}{1-D}$(14)

D is the duty ratio of switching pulse, V_{CS} is the capacitor voltage and V_L is the inductor voltage. V_o is the output voltage and V_{in} is the input voltage. The voltage gain (V_o/V_{in}) is necessary for duty cycle ratios. In real cases, the components are not ideal as given above.

III. DESIGN CONSIDERATIONS

The design should be appropriate in order to have a proper operation. Some disadvantages of proposed converter in DCM mode are slow dynamic response, dependence on output power, switching frequency, high current stress on the semiconductors and the value of the inductors. So, the proposed converter operates only in CCM mode with switching frequency 40kHz and input voltage 20V. Therefore, design of proposed converter in continuous conduction mode operation are presented here.

Inductor design

The input inductor depends on ripple current (Δi_L), inductor voltage (V_L), duty cycle (D) and switching frequency (f_s). In mode 1, the voltages of input inductor are equal to Vin. Therefore, the input inductance value is obtained by

$L1 = L2 = \frac{V_{in} * D}{\Delta i_L * f_s}$(15)

According to (2) and (7), the voltage of inductor L3 is equal to $2V_{CS}$. Therefore, the inductor value is obtained as

$L3 = \frac{2V_{in} * D}{\Delta i_L * f_s}$

(16)

The switching frequency is 40kHz, input voltage is 20V and duty cycle 0.85.

Capacitor selection

The value of C_O depends on V_O, the output power of the converter P_O, switching frequency f_S and voltage ripple ΔV_C. Therefore, the output capacitance value is obtained by

$Co = \frac{I_O D}{\Delta V_C f_s}$

(17)

Accordingly, the value of capacitor can be obtained as

$Cs = \frac{I_O}{\Delta V_C f_s}$

(18)

The output current is 0.7A, Duty cycle is 0.85 and switching frequency is 40kHz.

IV. COMPARISON WITH OTHER CONVERTERS

The proposed converter features are compared with other topologies like conventional SEPIC converter, buck-boost converter is provided in table I. The table shows the voltage gain is high in proposed converter than the classical SEPIC converters and boost converters. In table I, the voltage stress on switches are also compared. The number of components is also less in proposed converter. The proposed converter shows continuous input current as same as conventional SEPIC converter. The high voltage gain is achieved by using two switches, one diode, three inductor and two capacitor.

TABLE- I: Comparison between the proposed converter with other converters

Parameters	Proposed	SEPIC	Boost
Voltage gain	$\frac{2D}{1-D}$	$\frac{D}{1-D}$	$\frac{1}{1-D}$
Number of switches	2	1	1
Number of diodes	1	1	1
Number of inductors	3	2	1
Number of capacitors	2	2	1
Total device count	8	6	4

V. SIMULATION RESULTS

The circuit components are listed in table II. Pulse generator is used to generate pulse for switches of converter. The switching frequency in continuous conduction mode is 40kHz with 85% duty cycle. The simulation diagram for open loop and closed loop system is shown in Fig.3(a) and Fig.3(b) respectively.

The input voltage Vin is presented in Fig.4(a). The voltage (Vo) and current (I_O) are shown in Fig.4(b) and Fig.4(c) respectively. The voltage (V_O) with 85% duty cycle is 250V. Based on this figure, Vin is 20V. The proposed converter is applicable for renewable energy applications because it has continuous input current. The input inductor voltage and current are shown in Fig.4(d) and Fig.4(e) respectively. The voltage and current across inductor $L_3$is given in Fig.4(f) and Fig.4(g) respectively. The pulse generator pulse waveform is given in Fig.4(h). The voltage across capacitor CS is shown in Fig.4(i). The capacitor current CS is shown in Fig.4(j). The simulation results of proposed SEPIC converter shows the higher output voltage than other converters.

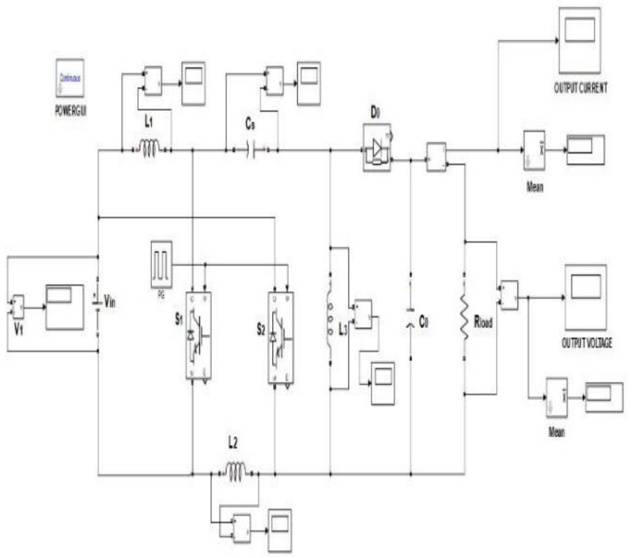

Fig.3(a) Open loop simulation diagram

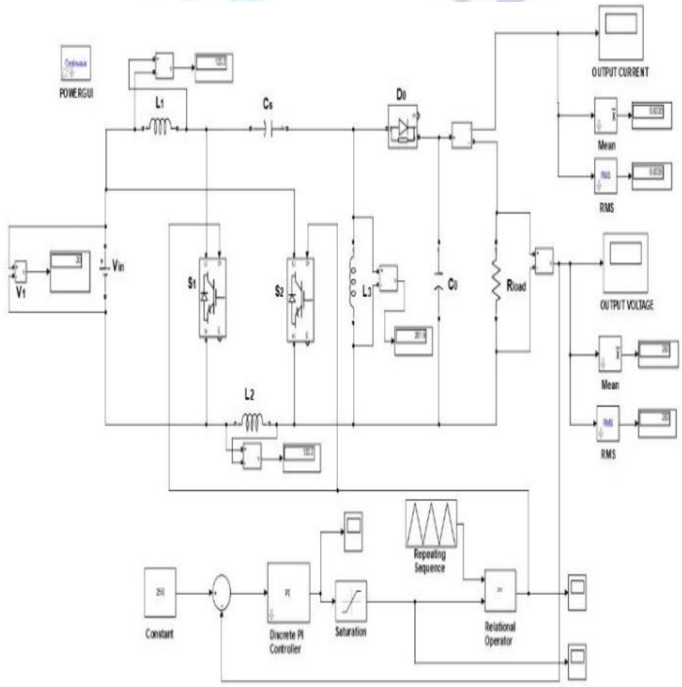

Fig.3(b) Closed loop simulation diagram

TABLE- II: Circuit parameters

Symbol	Quantity	Value
V_{in}	Input voltage	20V
f_s	Switching frequency	40kHz
L1, L2	Input inductor	123µH
L3	Third inductor	246µH
CS	Capacitor	4µH

C_O	Output capacitor	15µH
V_O	Output voltage	250V
P_O	Output power	200W

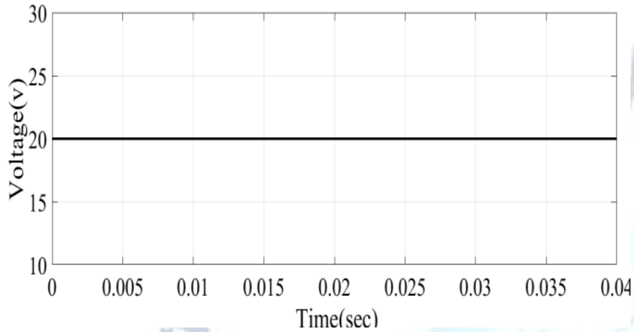

Fig.4(a) Input voltage of proposed SEPIC converter

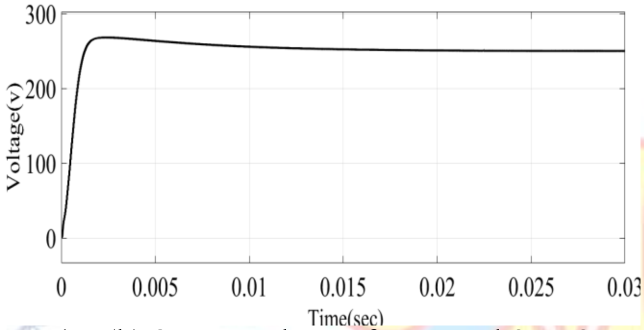

Fig.4(b) Output voltage of proposed SEPIC converter

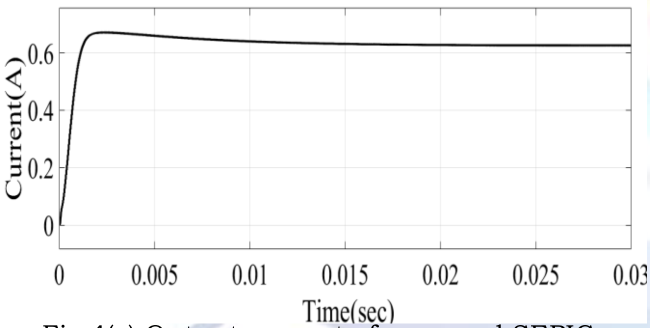

Fig.4(c) Output current of proposed SEPIC converter

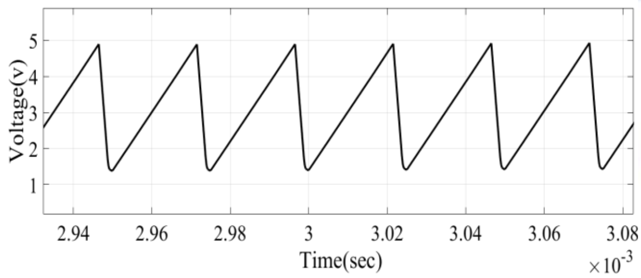

Fig.4(d) Output voltage of input inductors L1 and L2

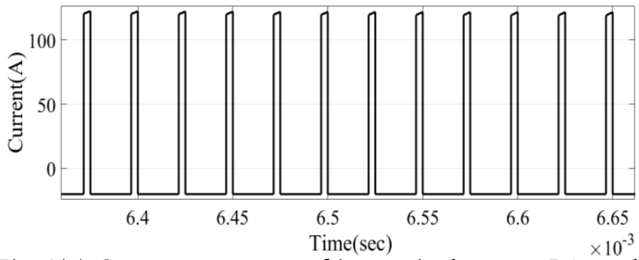

Fig.4(e) Output current of input inductors L1 and L2

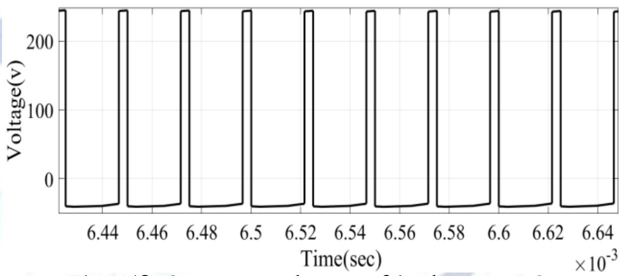

Fig.4(f) Output voltage of inductor L3

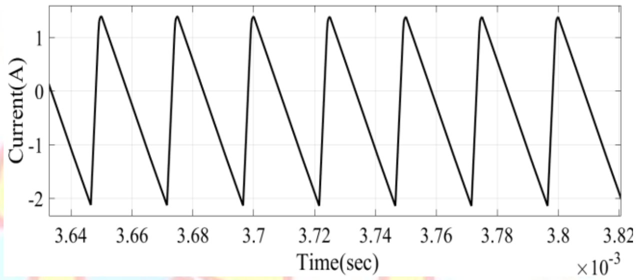

Fig.4(g) Output current of inductor L3

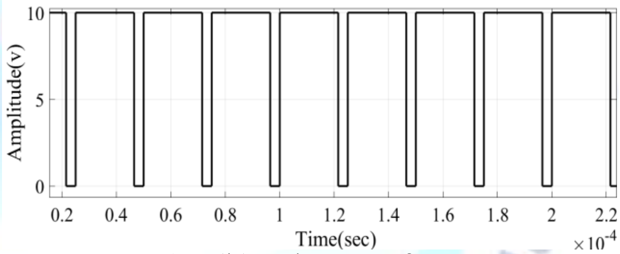

Fig.4(h) Pulse waveform

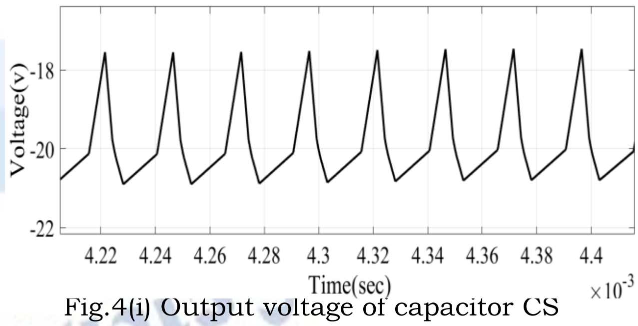

Fig.4(i) Output voltage of capacitor CS

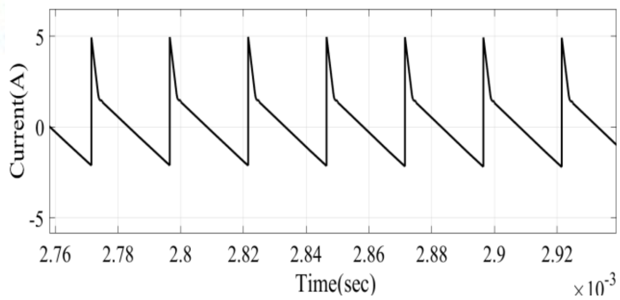

Fig.4(j) Output current of capacitor CS

The average current of input inductor is shown. The voltage across output capacitor is 250V. Measured values cause a little difference when compared with calculated values. Therefore, the proposed converter has lower conduction and switching losses than conventional SEPIC converter. No clamping circuit is needed to recycle the energy. The open loop simulations show the high gain output voltage by using pulse generator. The closed loop simulation shows the high gain output voltage by using PI controller technique.

VI. CONCLUSION

A high voltage gain modified SEPIC converter is proposed in this paper. The proposed converter is modified and simple. The modified SEPIC converter is tested with an input voltage of 20V at a switching frequency of 40kHz. The PI control for the proposed converter produces any desired output voltage ranging from 50V to 600V. The presented converter has manyadvantages i.e., non-inverting output voltage, lower voltage stress, high efficiency, voltage gain is high without any coupled inductor and transformer, continuous input current. The analysis of proposed converter under continuous conduction mode operation have been presented. Based on the results, the output voltage is higher than the other converters. To validate the advantages of proposed SEPIC converter, the simulation results were presented.

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