Design of SEPIC Converter using MATLAB

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Abstract - A SEPIC (single-ended primary inductor converter) is a DC-DC converter, capable of operating both in step-up or step-down mode. There are two possible modes of operation in SEPIC converter: continuous conduction mode (CCM) and discontinuous conduction mode (DCM). In this used the SEPIC converter operating in continuous conduction mode (CCM). Sepic converter widely used in battery operated equipments, NiMH charger, LED lighting applications, wide dc-input voltage range power supplies and automotive application. Buck and boost converter suffer from high amount of input current ripple and harmonics also they are expensive or insufficient.cuk converter solve problems of buck and boost converter by using capacitor and inductor. Both cuk and buck boost converter operating large amount of electrical stress, this can result in device failure or overheating. SEPIC converter solves both of these problems. In this paper focus on the SEPIC PFC (power factor correction) converter and design of digital controller base. Design and simulation 100w SEPIC PFC converter using MATLAB and also Prototype hardware was built accordingly.

Keywords - DC-DC converter, SEPIC converter, Comparison DC-DC converter, Specification, design ,state space modeling ,open loop, pwm.

1. INTRODUCTION

DC to DC converters convert one voltage level to another greater than, less than or equal to level voltage. They are used in various applications like, power supplies for personal computers (PC), office equipment, laptop computers, and Tele-communications equipment, industry as well as in research domain. The main thing that is required to be considered is the analysis and control of converters. Various control methods are used for control of dc-dc converters. but the method that gives the best performance under any conditions is always used in many application. The SEPIC converter is used as a dc to dc convert which is considered under the Switch Mode Power Supply. There are two types of of switch mode power supply.

(1) Non-Isolated Supply: No isolation between input voltage and output voltage.

(2) Isolated Supply: There must be isolation between an input voltage and output voltage for safety purpose.

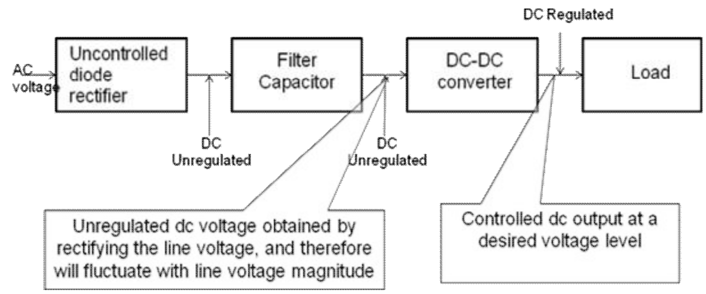


Figure 1 basic block diagram of DC-DC converter

In normal power supply AC voltage is present, so if DC voltage requires they conversion is must. Show in Fig AC input give the uncontrolled diode rectifier the output of this DC unregulated. This output goes next stage in filter capacitor and remove unwanted or undesired frequency. But also they output is DC unregulated only frequency is lesser.DC unregulated input give the DC-DC converter output give the regulated DC at a desired voltage level. This output connected with load. DC-DC converters are two control methods for DC-DC converters: voltage mode control and current mode control In voltage mode control, the output voltage of converter is compared with a reference signal. The error signals generated in the form of voltage. On the basis of error signal the duty cycle is set to follow the output voltage to the reference input. In current mode control two loops are used in which the inner current loop is added to the voltage loop. The current loop displays the inductor current and compares it with reference value generated by the voltage loop. In open loop SEPIC converter output is not maintained constant. In order to get the constant output, output voltage of SEPIC converter is continuously fed back and analyzes the results in terms of variation in input voltage, to get the desired output.

1.1 SEPIC converter:

similar to a traditional buck-boost converter, but has advantages of having non-inverted output (the output has the same voltage polarity as the input). The basic SEPIC DC-DC converter circuit diagram shown in Fig.2. It consists of semiconductor switch, a diode (D), an inductor (L1 and L2), a capacitor(C and C1).V_{in} denotes the input voltage and V_{Out} denotes the output voltage.

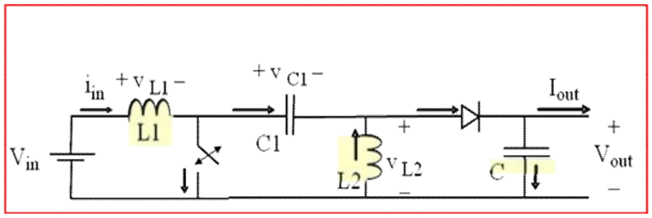


Figure 2 basic sepic converter

(1) Switch

The power switch can either be a MOSFET, IGBT, JFET or a BJT.

- MOSFET

The MOSFET is a voltage controlled device and have a positive temperature coefficient which stops the thermal runaway. MOSFET is preferred for higher frequencies but at lower voltage applications.

- IGBT

IGBT is used for low frequency and high voltage applications.

(2) Inductor

Inductor is used as energy storage device which limits the rate of current through the switch when switch is in on condition and controls the percent of the ripple and also determines the mode of operation of the circuit.

(3)Capacitor

Output capacitance (across the load) is used for filtering purpose and also minimizes the voltage overshoot and ripple present at the output of a step-down converter. The capacitor is large enough so that its voltage does not have any noticeable change during the time the switch is off.

(4) Freewheeling Diode

The purpose of Freewheeling diode is to direct current flow in the circuit and to ensure that there is always a path for the current to flow into the inductor. The Freewheeling diodes convert stored energy in the inductor to the load.

(5) Switching Frequency

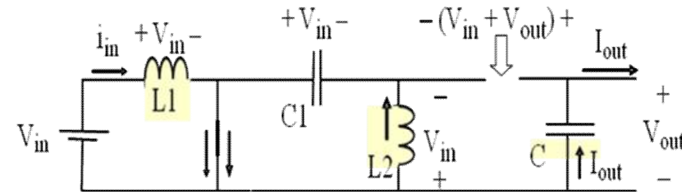
The switching frequency is determined by choosing the trade off between high value and value of switching frequency because at higher value the size of component is reduced but the switching losses will be increase and at lower value switching losses are reduced but component size will be increased

1.2 Operation of SEPIC converter:

The SEPIC converter operates in two modes of operation as sown in Fig 3 and Fig 4:

(1) When the switch is closed and (2) When the switch is open

When the switch is closed diode comes in reverse biased due to the cathode is more positive than anode and input voltage



supplies energy to the inductor (L1), capacitor (C1).Voltage across the inductor (L2) during capacitor (C1) is discharging. Voltage across output Vout is give capacitor (C) in this time capacitor (C) also discharge. Apply KVL $V_{c1} = V_{l1} = V_{in}$.

Figure 3 basic sepic converters ON state

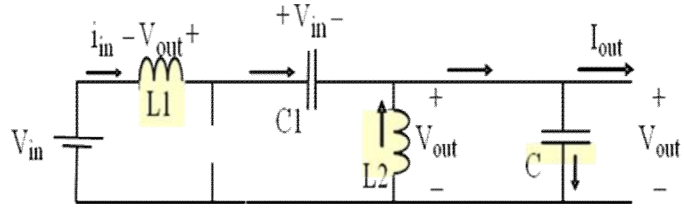


Figure 4 basic sepic converters OFF state

When the switch is open diode comes in forward biased and thus conduct because anode is more positive than cathode and the capacitor supplies energy to Vout , and the inductor (L1) . current flows through the capacitor (C1) and the diode. Inductor discharges causing its voltage polarity to be reversed. At this time capacitor (C1 and C) is charging mode. Apply KVL $V_{l1} = V_{out}$.

$$(V_{l1}, sw\ closed)(DT) + (V_{l1}, sw\ open)(1-D)T = 0$$

$$V_{in}(DT) - V_{Out}(1-D)T = 0$$

Where D= Duty Cycle = (Ton/T)

The result is,

$$D = \frac{V_{out}}{V_{out} + V_{in}}$$

This equation shows that the output voltage is obtained by input voltage multiply with duty cycle. i.e. The output voltage of SEPIC converter is always less than, greater than and equal the input voltage.

1.3 Mode of SEPIC converter:

According to the continuity of inductor current dc-dc converter has two modes of operation:

(1) Continuous Conduction Mode (CCM): In this mode the inductor current continue to low shown in Fig5. In most of the applications of SEPIC converter, the inductor current

never falls to zero during full-load operation and overall performance is usually better, and it allows maximum output power to be obtained from a given input voltage and switch currentrating.

Figure 5 continuous conduction mode

(2) Discontinuous Conduction Mode (DCM): In this mode the inductor current falls to zero and stay at zero for specified period of switching cycle shown in Fig6. It starts at zero, reaches a peak value, and returns to zero during each switching cycle. It is used in the applications where the maximum load current is fairly low which can reduce the overall size of the converter.

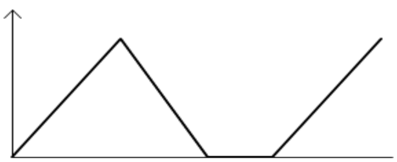


Figure 6 Discontinuous conduction modes

2. STATE SPACE MODELING

There are different kinds of averaging modeling methods for a given power stage: the state-space averaging method, the PWM switch modeling method and the circuit average method. In this thesis, the state-space method, which describes an averaging model of the system during 1 switching cycle, is adapted to analyze the SEPIC converters. Given that the SEPIC converter is operating in CCM, there are 2 time intervals during 1 switching cycle, T, for which: switch S1 has an on-time, (d) T and an, off-time, (1-d)T, where d is the duty cycle. The state-space equations over 1 cycle can be expressed according to:

Where:

$$u = [Vin] \qquad x = \begin{bmatrix} \frac{diL1}{dt} \\ \frac{diL2}{dt} \\ \frac{diVc1}{dt} \\ \frac{diVc2}{dt} \end{bmatrix}$$

2.2 State space modelling for ON stage:

Apply the circuit fig 2 KVL and KCL and measure this equation:

The voltage across L1 is the same as input voltage, Vin:

$$L1\left[\frac{diL1}{dt}\right] = Vin$$

The voltage across Lo is the same as the voltage across capacitor, C1:

$$L2\left[\frac{diL2}{dt}\right] = Vc1$$

The current through C1 is the same as the current through inductor L2:

$$C1\left[\frac{dVc1}{dt}\right] = -iL0$$

The current through C2 is the same as the load current.

$$C2\left[\frac{dVc2}{dt}\right] = \frac{-Vout}{R}$$

2.3 State space modelling for OFF stage:

Apply the circuit fig 3.2.1 KVL and KCL and measure this equation:

The voltage across L1 is the same as the input voltage, Vin:

$$L1\left[\frac{diL1}{dt}\right] = Vin - Vc1 - Vc2$$

The voltage across L2 is the same as the capacitor voltage, C1:

$$L2\left[\frac{diL2}{dt}\right] = -Vc2$$

The current through C1 is the same as the current through inductor, L2:

$$C1\left[\frac{dVc1}{dt}\right] = iL1$$

The current through C2 is the same of the current through two inductors and load:

$$C2\left[\frac{dVc2}{dt}\right] = iL1 + iL2$$

According to equation find the A1, A2, B1 and B2.

2.4 State space averaging matrix modelling:

State space averaging matrix and small signal analysis:

$$B = B1 * d + B2 * (1 - d)$$

$$X = A^{-1} * B * Vin$$

$$F = [(A1 - A2) * X + (B1 - B2) * Vin]$$

Transfer function output by input:

Transfer function output by duty cycle:

$$\left(\frac{Vo}{d}\right) = A(SI - A)^{-1} * F$$

So the transfer function output by input is :

$$\frac{5s^3 + 1.665*10^6 s^2 + 7.284*10^7 s + 1.041*10^{13}}{s^4 + 393 s^2 + 7.933*10^6 s^2 + 2.319*10^9 s + 1.045*10^{13}}$$

This transfer function is fourth order. so they solution is so complexes .so they reduce the order.

3. SIMULINK DESIGN OF PROPOSED SYSTEM

3.1 Design specification:

The SEPIC converter is designed by using the specifications shown in Table 3.1:

Calculation of L and C:

For designing a SEPIC converter the first step is required to calculate the values of inductor and capacitor based on the equations.

The value of inductor is determined by,

Table 3.1.1 design specification

Parameter	Value
DC input voltage(V_{in})	10V
Output Voltage(V_{out})	10V
Switching Frequency(F_s)	50KHZ
Output Current (i_o))	10A
Maximum Power (P_{max})	100W

By using the equations and parameter specifications given in Table 2 calculated value of inductor and capacitor shown in Table 3.2

Table 3.1.2 component selction

Component	Value
Inductor (L1)	100µH
Inductor (L2)	100µH
Capacitor (C1)	800µF
Capacitor (C2)	3000µF

By using this basic sepic converter specification design a open loop simulink.

3.2 Open loop simulink model:

The SEPIC converter is simulated in Matlab/Simulink using the basic circuit diagram of SEPIC converter (Fig2), the specifications (Table 3.1.1) and the selected value of components (Table 3.1.2) as shown in Fig6.

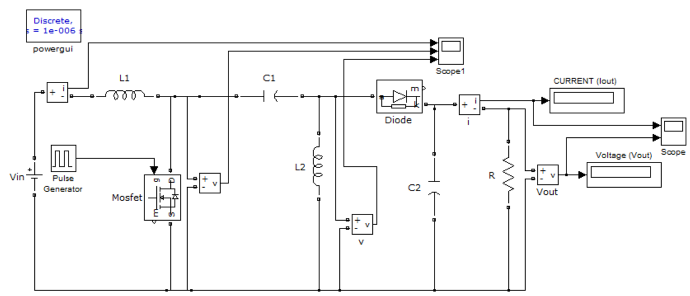


Figure 6 Discontinuous conduction modes

In order to generate the pulse PWM (Pulse Width Modulation) is used. The logic of PWM is shown in Table 3.2.

Table 3.2 PWM logic

T	D	F
On	Off	1
Off	On	0

PWM Logic is developed in MATLAB as shown in Fig7.

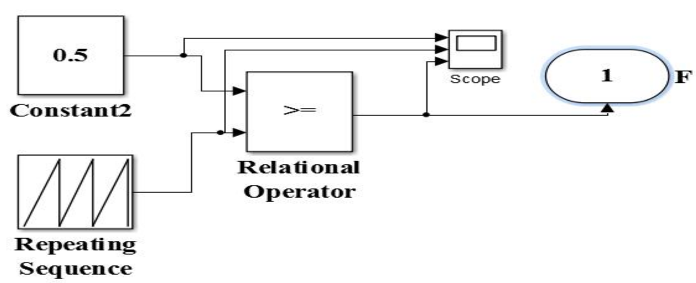


Figure 7 PWM logic matlab simulation

4. EXPERIMENTAL RESULT

After designing the open loop SEPIC converter in Simulink the response is shown in Fig.8 and Fig.9 for varying input voltage.

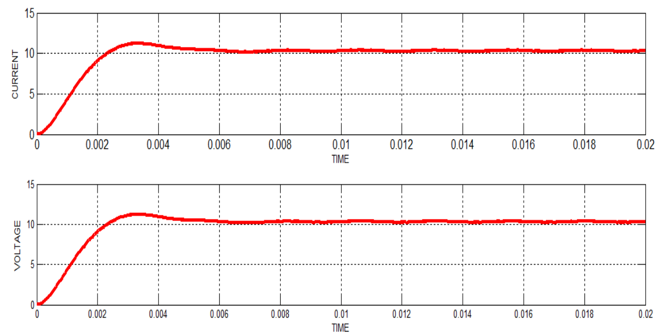


Figure 8 Open-Loop SEPIC Converter Response for V_{in}=10V

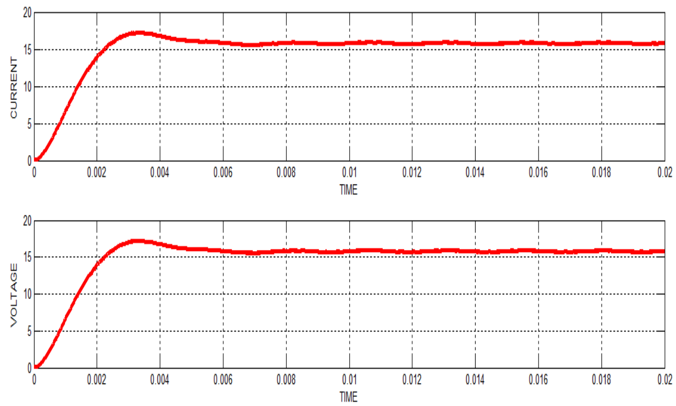


Figure 9 Open-Loop SEPIC Converter Response for V_{in}=15V

Table 4.1 error measurement open loop

V_{dc}	V_o(desired)	I_o(desired)	V_o(actual)	I_o(actual)	Error (V_o)	Error (I_o)
10 V	10V	10A	10.13 V	10.13 A	0.13V	0.013 A
15 V	10V	10A	15.79 V	15.79 A	- 5.79V	5.79A

From this Table (4.1) it can be concluded that because the variation in input voltage output voltage and output current is not maintained constant.

5. CONCLUSION

SEPIC converter open loop converter output is not maintained constant as we don't check on its parameters like output current or voltage and fixed duty cycle to get the theoretically calculated output voltage. To overcome this closed loop is used in which output can be get constant by varying duty cycle. Output voltage is continuously measured and compared with reference voltage. Depending upon the mismatch between the desired voltage and the actual output voltage, the controller varies the duty-cycle continuously to get the correct output.

6. FUTURE SCOPES

In this research paper open simulink and show out response and they output is not constant if any change in supply and parameter this disadvantage neglected using closed loop using. In closed loop PID controller as well as another any controller used and output remaining constant.

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