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Analysis and Non-linear Control of sepicdc-dc converter

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ABSTRACT

SEPIC converter has various applications as a power conditioning system because it has a non-pulsating input current and its voltage can be either stepped-down and stepped-up. However, due to the non-linear characteristics of a this type converter, non-linear control techniques are more suitable to attain better performance in voltage regulation. Due to load and output voltage variations, good performance can be achieved through the Non-linear Control because SEPIC converter is a Non-linear system. The performance of the developed controllers with the SEPIC converter is performed through Matlab environment. The proposed system is suitable for all real-world commercial applications, like the power supplies for medical equipment, computer power supplies, uninterrupted power supplies, etc. Various control techniques such as PI controller, fuzzy logic controller, sliding mode controller are used for analysis using Matlab and results are made to compare. The results are compared for change in load variations

Keywords : Converter, Dynamic Performance, Voltage Regulation,Non-Linear Control, Sepic, Smc.

Abbreviations and Acronyms : CCM-Continuous Conduction Mode;VRM-Voltage Regulator Module;SMC-Sliding Mode Controller;FLC-Fuzzy Logic Controller;D-Dutycycle;SEPIC-Single Ended Primary Inductor Converter; MOSFET-Metal Oxide Semiconductor Field Effect Transistor

I. INTRODUCTION

A DC-DC type of converter is a small, light, and highly efficient DC power supply using semiconductor switching elements. DC to DC converters are generally used to convert an input DC voltage to an output DC voltage. Such converters may step down or step up the input DC voltage. Due to their ability to receive low input voltages and consume low power, DC-DC converters have been widely used in all types of electronic products. A DC-to-DC converter provides the functions of regulating the voltage level from a DC input voltage, such as boost or buck voltage conversion, and of maintaining the regulated voltage at the desired level. DC to DC converters are widely used for battery-powered electronic equipment, renewable energy systems, and voltage regulator modules (VRM) to produce a regulated voltage or current derived from an unregulated power supply. This converter is called a switch-mode power supply. The basic converter topologies such as CUK and SEPIC and etc., converters can be implemented for this analysis. The project is proposed with sepic converter which is used to improve the dynamic performance, using various control techniques such as PI controller, fuzzy logic controller and sliding mode controller.

The most commonly used converter is a boost converter. Boost converters are step-up converters in which output a voltage higher than the voltage that is input to the converter. The standard boost converter has an output that is equivalent to the input voltage divided by the duty cycle.

$$V_{out} = \frac{V_{in}}{(1-D)} \qquad .....(1)$$

A sliding mode controller for the SEPIC is proposed to ensure the stability under any operating conditions, and to have a better static and dynamic performances for any change in its input as well as load changes and component variations. In sliding mode control, a state trajectory moves back and forth around a certain average surface in the state space. Four sliding variables are considered in this paper since the SEPIC is a fourth order system. The SMC control technique offers several advantages such as stability even for a large supply and load variations, robustness, good dynamic response and simple implementation. Its capabilities result in improved.

II. SEPIC CONVERTER

A SEPIC is a DC-DC converter which has the ability to convert input voltage to an output voltage which can be stepped up or stepped down . The switch of the SEPIC is controlled by changing the duty cycle. This enables close and open conditions. A SEPIC is like a buck-boost converter. However, it has the unique feature of giving a non-inverted output. This means that the output is always the same polarity as the input. A series capacitor is used to couple the energy from the input to the output. The SEPIC can respond quickly to a short-circuit condition, and it works as a true shutdown mode when the switch is turned off and its output drops to 0V following a fairly hefty transient dump of charge.

The SEPIC is useful in applications in which the voltage can be above or below that of the regulator's intended output. The SEPIC transfers energy through the switching operation between the capacitors and the inductors. This is done in order to convert from one voltage to another. The amount of energy is controlled by switch S, which is a transistor such as a MOSFET, IGBT, etc. MOSFET offer a much higher input impedance and a lower voltage stress and do not require biasing resistors. In addition, MOSFET switching can be controlled by differences in voltage rather than a current.

III. MODES OF OPERATION

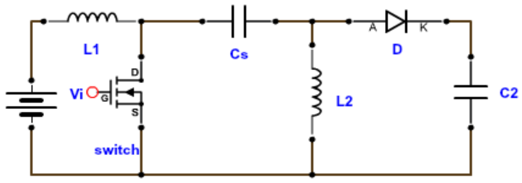


Figure 1. Circuit diagram of sepic converter

Figure 1.shows the circuit diagram of single ended primary inductor capacitor. 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 in inductor L1 is coming from the input source.

A SEPIC is said to be in continuous-conduction mode if the current through the inductor L1 never go down to zero. During a SEPIC's steady-state operation, the average voltage across capacitor C_S (V_{CS}) is equal to the input voltage (V_{IN}). Because capacitor C_S blocks direct current, the average current across it (I_{CS}) is zero, making inductor L3 the only source of load current. Hence the average current through inductor L3 is the same as the average load current and hence independent of the input voltage. Looking at average voltages, the following can be written:

$$V_{IN}=V_{L1}+V_{CS}+V_{L2} \quad \text{….(2)}$$

Because the average voltage of V_{CS} is equal to V_{IN}

$$V_{L1}=-V_{L2}. \quad \text{…..(3)}$$

For this reason, the two inductors can be wound on the same core. Since the voltages are the equal in magnitude, their mutual inductance effect will be zero. Here it is assumed that the polarity of the coil is correct. As the voltages are the equal in magnitude, the ripple currents of the two inductors will be equal in magnitude.

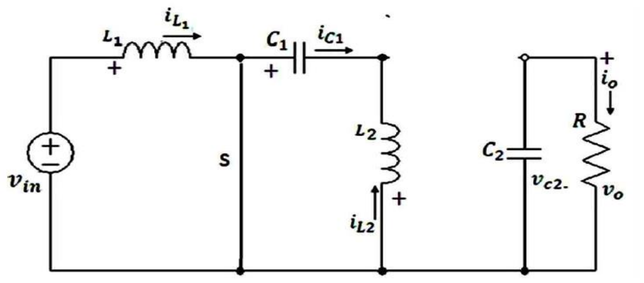


Figure 2. Switch ON condition

Figure 2.shows the working condition of sepic converter during ON state. When switch is turned on, current IL1 increases and the current IL3increases in the negative direction. The energy to increase the current IL1 comes from the input source. Since Q1 is a short while closed, and the instantaneous voltage VCs is approximately VIN, the voltage VL3is approximately –VIN. Therefore, the capacitor Cs supplies the energy to increase the magnitude of the current in IL3and thus increase the energy stored in L3.

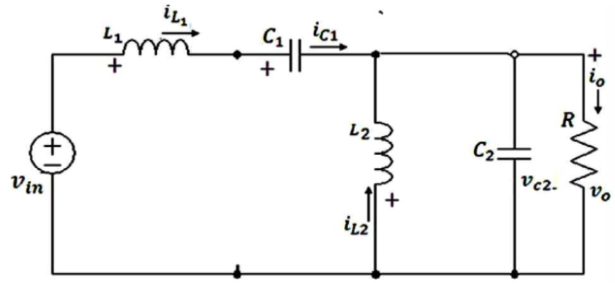


Figure 3. Switch OFF condition

Figure 3.shows the working condition of sepic converter during OFF state. When switch (Q1) is turned off, the current ICs becomes the same as the current IL1, as the inductors will not allow instantaneous changes in current. Current IL3will continue in the negative direction, in fact it never reverse direction. It can be seen from the diagram that a negative IL3will add to the current IL1 to increase the current delivered to the load.

By Using Kirchhoff's Current Law

ID1 = ICs–IL2. …..(4)

So while switch is off, power is delivered to the load from both L3and L1. Coupling capacitor (Cs), is charged by L1 during this off cycle, and will recharge L3 during the on cycle. The boost/buck capabilities of the SEPIC are possible because of capacitor Cs and inductor L3. Inductor L1 and switch Q1 create a standard boost converter, which generates a voltage (VQ1) that is higher than VIN. Its magnitude is determined by the duty cycle of the switch Q1. Since the average voltage across Cs is VIN, the output voltage (VOUT) is

VOUT=VQ1-VIN. …..(5)

If VQ1 is less than double of VIN, then the output voltage will be less than the input voltage. If VQ1 will be greater than double of VIN, then the output voltage will be greater than the input voltage.

B. DESIGN EQUATIONS

DUTY CYCLE

$$D = \frac{V_o}{V_o+V_{in}} \quad …..(6)$$

INDUCTANCE

$$L1 = L2=\frac{DV_{in}}{f\ \Delta I_L} \quad …..(7)$$

CAPACITANCE

$$C1 = \frac{I_o\ D}{f\ \Delta V_{c1}} \quad …..(8)$$

$$Co= \frac{I_o\ D}{f *0.5*\Delta V_{c2}} \quad ......(9)$$

C. DESIGN PARAMETERS

Input line voltage (V_s) = 12V
Output voltage = 48V
Output power = 46W
Switching frequency = 100 kHz
Duty cycle (d) = 0.8

Line frequency (fs) = 50Hz
Inductance (L1=L2) = 110μH
Capacitance C_1 = 5μF
Capacitance C_2 = 300μF
Load resistance = 50 Ω
Load inductance = 110μF

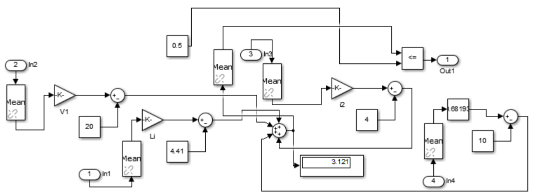
IV. DESIGN OF SMC FOR SEPIC

The design of smc for sepic converter is obtained by deriving its mathematical model using state space averaging technique.

A. MATHEMATICAL MODELLING OF SEPIC

The advantage of mathematical modelling is to handle the system easily with several inputs and outputs. The system model includes the internal state variables and the output variable. The model directly provides a time-domain solution, which ultimately is the thing of interest. The effect of the initial conditions can be incorporated into the solution and the matrix modelling is very efficient from a computational standpoint for computer implementation.

The state variables of the sepic converter here considered are x1,x2,x3 and x4 which is inductor currents(iL1 and iL3) and capacitor voltages (Vc1 and Vc2) respectively.



When the switch is turned on the state space equation can be obtained as

$$\dot{x}_1 = -\frac{v_{in}}{L_1}$$

$$\dot{x}_2 = \frac{v_{c_1}}{L_2}$$

$$\dot{x}_3 = -\frac{i_{L_2}}{C_1}$$

$$\dot{x}_4 = -\frac{v_{C_2}}{RC_2}$$

$$\frac{d}{dt}\begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L_2} & 0 \\ 0 & \frac{-1}{C_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{RC_2} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_2} \end{bmatrix} + \begin{bmatrix} \frac{-1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} v_{in}$$

When the switch is turned off the state space equation can be obtained

$$\dot{x}_1 = -\frac{v_{C_1}}{L_1} - \frac{v_{C_2}}{L_1} + \frac{v_{in}}{L_1}$$

$$\dot{x}_2 = -\frac{v_{C_2}}{L_2}$$

$$\dot{x}_3 = \frac{i_{L_1}}{C_1}$$

$$\dot{x}_4 = \frac{i_{L_1}}{C_2} + \frac{i_{L_2}}{C_2} - \frac{v_{C_2}}{RC_2}$$

$$\frac{d}{dt}\begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L_1} & \frac{-1}{L_1} \\ 0 & 0 & 0 & \frac{-1}{L_2} \\ \frac{1}{C_1} & 0 & 0 & 0 \\ \frac{1}{C_2} & \frac{1}{C_2} & 0 & \frac{-1}{RC_2} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_2} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} v_{in}$$

The state space averaging technique,

$$\frac{d}{dt}\begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L_1} & \frac{-1}{L_1} \\ 0 & 0 & 0 & \frac{-1}{L_2} \\ \frac{1}{C_1} & 0 & 0 & 0 \\ \frac{1}{C_2} & \frac{1}{C_2} & 0 & \frac{-1}{RC_2} \end{bmatrix} \begin{bmatrix} i_{L_1} \\ i_{L_2} \\ v_{C_1} \\ v_{C_2} \end{bmatrix} + \begin{bmatrix} \frac{v_{C_1} + v_{C_2} - 2v_{in}}{L_1} \\ \frac{v_{C_1} + v_{C_2}}{L_2} \\ \frac{-i_{L_1} - i_{L_2}}{C_1} \\ \frac{-i_{L_1} - i_{L_2}}{C_2} \end{bmatrix} y + \begin{bmatrix} \frac{1}{L_1} \\ 0 \\ 0 \\ 0 \end{bmatrix} v_{in}$$

$$\dot{X} = AX + By + C$$

The status of the switch is

$$y = \begin{cases} 1 \rightarrow S \rightarrow ON \\ 0 \rightarrow S \rightarrow OFF \end{cases}$$

The system response is determined by the circuit parameters and coefficients k1,k2,k3 and k4. With a proper selection of these coefficients under any operating conditions, high control strength, performance and a quick sepic output response can be achieved.

V. RESULTS AND DISCUSSION

The main purpose of this section is to analyse the simulation studies of the sepic with four different control methods. The simulation are performed on the SEPIC 's circuit with the following conditions:

1. Without controller
2. With PI controller
3. With FLC
4. With Sliding mode controller

1. Without a feedback controller :

The SEPIC is simulated using a pulse generator which is connected to the MOSFET gate to give a pulse input with a frequency of 100KHz. It is found that in the absence of controller ,the voltage is not maintained with 48V. The duty ratio is 80% as calculated from the given specifications.

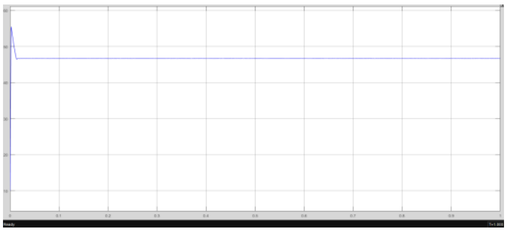


Figure 4. Open loop analysis of SEPIC converter

From figure 4 ,it is found that the voltage is regulated upto 45.31V in the absence of controller.

TABLE 1 : Performance analysis of SEPIC Converter with PI controller

% of load	Output voltage	Output power
100	48	46.08
75	48	38.4
50	48	23.54
25	48	17.01

2. With PI controller :

The Ziegler-nichols method is applied for determining the values of Kp and Ki. The values of Kp and Ki are 0.0001 and 0.1.

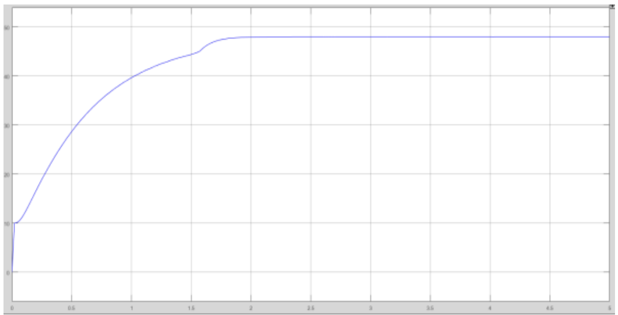


Figure 5. Closed loop analysis of SEPIC converter with PI controller.

3. With FLC :

One of the most commonly used soft computing technique is fuzzy logic based controller. The main purpose of FLC is to regulate the output voltage in the proposed system. Mamdani inference system is used here.

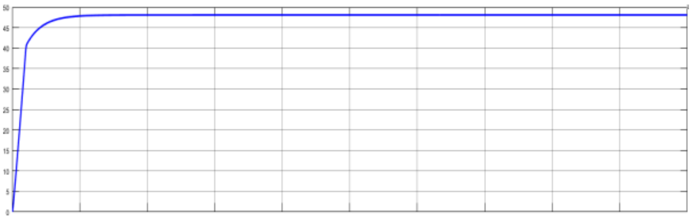


Figure 5. Closed loop analysis of SEPIC converter With Fuzzy logic controller.

% of load	Output voltage	Output power
100	48	45.1296
75	48	37.768
50	48	32.13
25	48	23.725

TABLE II.Performance analysis of sepic with FLC controller.

4. With Sliding mode controller:

The parameters of the sliding mode controller which is calculated as per mathematical modelling of sepic are:

K1=K2=0.599,K3=0.378,K4=0.227.

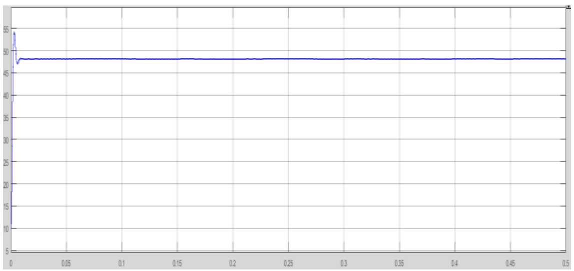


Figure 6. Closed loop analysis of SEPIC converter with SMC controller.

% of load	Output voltage	Output power
100	47.99	46.07
75	48.01	38.408
50	48.03	28.67
25	48.15	21.66

TABLE III. Performance analysis of sepic with sliding mode controller .

VI. CONCLUSION

The DC-DC SEPIC converter was simulated with variation in load. The voltage unbalance problem is improved by using proposed SEPIC converter. Mathematical modeling of the sepic converter is derived. The simulation was done for PI controller, fuzzy logic controller and sliding mode controller with variations in load. Fuzzy controller is easy to implement which provides crisp output and good robustness against load variation. Sliding mode controller for the sepic converter is proposed in order to ensure the stability under any operating conditions, better static and dynamic response under load variations. This system is suitable for real world applications lie power supplies for medical equipment, computer power supplies, uninterrupted power supplies, etc. The scope of the proposed system is suitable for real world commercial applications like power supplies for medical equipment, computer power supplies, uninterrupted power supplies, etc.

VII. Acknowledgment

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VIII. References

[1]. SubhashChander, ,Pramod Agarwal and Indra Gupta, " Auto tuned discrete PID controller for DC-DC converter for fast transient response" 978-1-4244-7882-8/11/$26.00 ©2011/ IEEE.

[2]. Tadi G L Krishna Reddy,RamamurthyRaju.P, Revanthkumar.V, "Analysis of sepic for pv applications using PI and current mode controller", IJSRD-International Journal of Scientific and Research Development ,vol .1,issue 9,2013.

[3]. Amit Patel ,Kamal Singh ,Sandeep Kumar Singh, "Study and simulation analysis of single ended primary inductance conductor ", International Journal of Inventions in Reasearch, Engineering

Science and Technology (IJIREST),Vol.1,No.1,April 2014.

[4]. Abhinav Dogra, Kanchan Pal, “Designing and tuning of PI controller for flybackconverter”,*International Journal of Engineering Trends and Technology (IJETT) – Volume 13 Number 3- Jul 2014***.**

[5]. Eduardo I.ortiz-rivera, Jesus Gonzalez-Llorente, John E.salazar-Duque, “analysis and non-linear control of sepic dc-dc converter for photovoltaic systems”, 978-1-4673-7653-5/15/$31.00 ©2015 /IEEE.

[6]. Venkatanarayanan Subramanian †and SaravananManimaran, “ Implementation of a sliding mode controller for single ended primary inductor converter”, Journal of Power Electronics, Vol. 15, No. 1, pp. 39-53, January 2015.

[7]. “Designing DC/DC converter based on sepictopology”,by Jeff falin, power management corporation.

[8]. Designing a SEPIC converter, National Semiconductor Application Note 1484,

Wei Gu, Dongbing Zhang April 30, 2008