Design and Simulation of Open Loop and Closed Loop Control for SEPIC Converter Using State Space Analysis

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Abstract—this paper present complete design and matlab Simulink of open loop and closed loop Sepic. Sepic convertor can work in CCM (Continuous Conduction Mode) and DCM (Discontinuous Conduction Mode) but here CCM consider and find out all element values for open loop Sepic Convertor and for closed loop control SSA (State Space Analysis) technique use which provide fourth order transfer function. By using transfer function PID Controller tune in matlab Software. Both open loop and closed loop matlab Simulink model show with output voltages.

Keywords—DC-DC Convertor; SSA; PID;

I. INTRODUCTION

This paper present design and Simulink model of open loop and closed loop Sepic converter. Volt-sec balance and I-sec balance equations use for designing elements values and input and output voltage relationship with duty cycle. SSA (State space analysis) use for finding transfer function of Sepic converter.
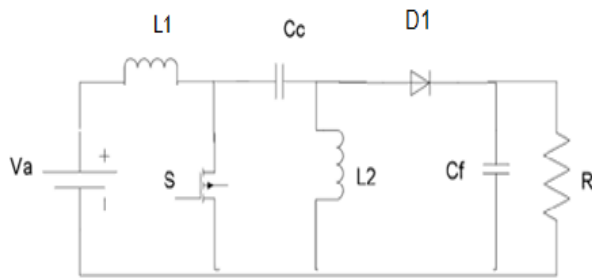
Fig. 1. Conventional SEPIC Converter (When MOSFET ON)

DC-DC convener plays an important role in our day to day life, for step up or down the voltages. Buck converter use for step down the voltage and boost convener use for step up the voltage. But both these converter have their significant role like either they can operate step up or step down the output voltage**.** Buck boost converter can operate in both mode but it has some disadvantage like output is inverting which is not useful in many applications. So to avoid this problem Sepic converter can use. Sepic converter firstly presented in 1977 by R.P. Massey and E.C. Snyder in this paper this converter use for high voltage applications with isolated transformer, inductor was connected to the primary of isolated converter so the name was given

primary inductor [1]. Again this converter represented by Marias K. Kazimierczuk and Jacek Jozwik with and without trasformer[2]. Now SEPIC converter use for various applications like solar system [3], PFC (power factor correction) [4], For Battery charging application. Figure I shows the conventional Sepic converter operation of Sepic Converter consist of two part when MOSFET is ON and when MOSFET is OFF.
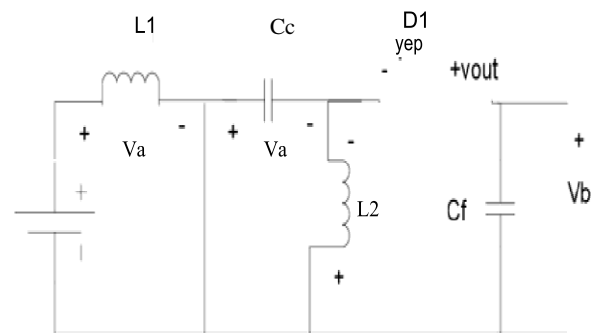

Fig. 2. Operation (When MOSFET ON)

CCM mode considers here it means that current in inductor never falls to zero. When S ON inductor L1 charge to Va and average voltage across capacitor also Va and voltage across inductor L2 is —Va so this reason we can wound inductor Ll and L2 on same core. Due to negative polarity anode of diode, diode will not conduct so no current flowing through the diode. At this time Output voltage maintained by Filter capacitor.
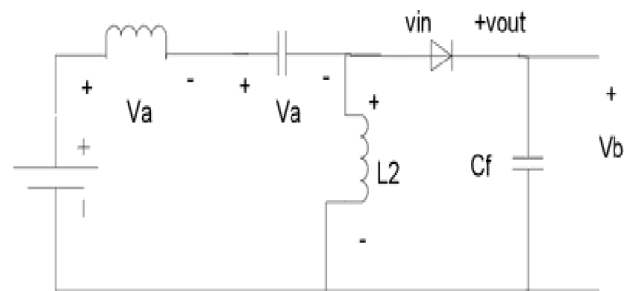

Fig. 3. Operation (When MOSFET OFF)

When MOSFET is OFF polarity of inductor will reverse as shown in figure but even though polarity changes current

through inductor will not changes instantly. It will change if the width of MOSFET is too long and current through inductor will reverse the direction and converter fails.so width of pulse should less. Due to Changing polarity of inductor diode D anode is more positive with respect to cathode and diode will ON and current flowing through it. Theoretical waveform shown below
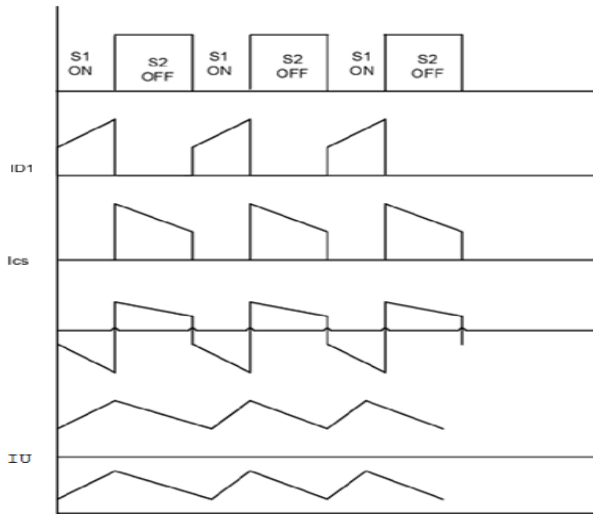

Fig. 4. Sepic Converter Wave Form

Fig. 5. Inductor Current Waveform

II. VOLT-SEC BALANCE EQUATION

From the above graph,
Consider Area A1=A2,

$Va*Ton=Vb*Toff$

Dividing both side by T

$$\frac{(Va*Ton)}{T} = \frac{Vb*Toff}{T}$$

$$Va*Don = Vb*Doff$$

$$\frac{Vb}{Va} = \frac{Don}{Doff}$$

$$\left(\frac{Vb}{Va}\right) = \frac{D}{1-D}$$

D=0.5 neither BUCK nor BOOST.

D<0.5= Buck Converter.

D>0.5= Boost Converter.

I - SEC BALANCE EQUATION

$$IaL1*Va = Ib*Vb$$

$$IaL1 = Ib*\frac{Vb}{Va}$$

$$IaL1 = Ib*\frac{Don}{Doff}$$

III. DESIGN SPECIFICATIONS

Consider the following values::

6v to 18v

Vb = 10 V

Ib =1 A

Fsw = 30k

Output Ripple Current Acceptable Δi = 0.5

Output Ripple Voltage Acceptable Δv = 0.1

Duty Cycle Consideration

$$Vb = \left(\frac{D}{1-D}\right)*Va$$

$$Vb + Vd = \left(\frac{D}{1-D}\right)*D$$

$$\frac{Vb+Vd}{Va} = \left(\frac{D}{1-D}\right)$$

$$(Vb+Vd)*(1-D) = D*Va$$

$$(Vb+Vd) - D(Vb+Vd) = D*Va$$

$$Vb+Vd = D*Va + D(Vb+Vd)$$

$$Vb+Vd = D*(Va+Vb+Vd)$$

$$D = \frac{Vb+Vd}{Va+Vb+Vd}$$

Diode drop we consider 0.5 here.

$$Dmin = \frac{Vb+Vd}{Va(min)+Vb+Vd}$$

$$Dmin = \frac{10+0.5}{6+10+0.5}$$

$$Dmax = \frac{Vb+Vd}{Va(max)+Vd+Vb}$$

$$Dmax = \frac{10+0.5}{18+0.5+10} = 0.3684$$

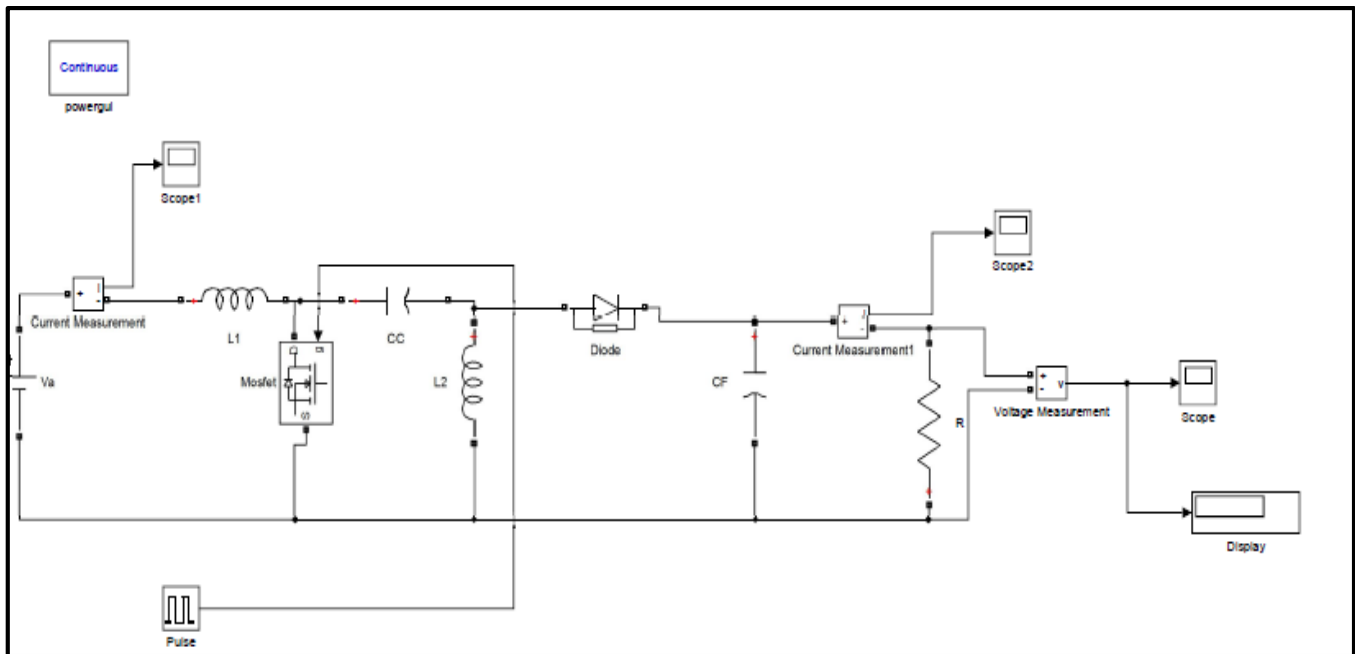Fig. 6 Matlab Simulink model of open loop Sepic Convertor

Inductor calculation:

$$VL = Vb$$

$$VLon = Va$$

$$L\frac{dILon}{dt} = Va$$

$$L\frac{\Delta IL}{dt} = Va$$

$$\Delta IL = \frac{Va * DT}{L}$$

$$\Delta IL = \frac{Va * Dmax}{LFsw}$$

$$L1 = \frac{6 * 0.6363}{50K * 0.5} = 151.2\mu H$$

$$L1 = 151.2\mu H$$

Filter capacitor calculation:

$$Icon = -Ib$$

$$Cf * \frac{dVc}{dT} = -Ib$$

$$dVc = -\frac{Ib * dt}{c}$$

$$\int_{Vmax}^{Vmin} dVc = \int_{D}^{DT} -\frac{Ib * dt}{Cf}$$

$$\Delta Vc = \frac{Ib * Dmax}{Cf * Fsw}$$

$$Cf = \frac{Ib * Dmax}{\Delta Vc * F * 0.5}$$

$$Cf = \frac{1 * 0.6363}{0.1 * 50K * 0.5} = 252\mu F$$

Coupling capacitor calculation:

$$CC = \frac{Ib * Dmax}{\Delta Vc * Fsw}$$

$$CC = \frac{1 * 0.63}{0.1 * 50K} = 126\mu F$$

Diode selection:

Peak Voltage across Diode = Va max + Vb max

= 18+10 = 28V

Closed loop analysis of Sepic converter:

When MOSFET ON) during 0<t<D

$$Va + L1\frac{dIL1}{dt} = 0$$

$$\frac{dIL1}{dt} = -\left(\frac{Va}{L1}\right)$$

$$L2\frac{dIL2}{dt} - Vcc = 0$$

$$\frac{dIL2}{dt} = \frac{Vcc}{L2}$$

$$CC\frac{dVcc}{dt} + IL2 = 0$$

$$\frac{dVc}{dt} = -\frac{IL2}{CC}$$

$$Cf\frac{dVcf}{dt} + \frac{Vcf}{R} = 0$$

$$\frac{dVcf}{dt} = -\frac{Vcf}{R*Cf}$$

Fig. 7 Open loop Sepic Convertor with 36.84 % duty Cycle at 18 Volt

Fig. 8 Output of open loop Sepic Convertor when duty cycle is 0.6363 at 6 V

When Mosfet off During D < t < (1-D)

$$Va + L1\frac{dIL1}{dt} + Vcc + Vcf = 0$$

$$\frac{dIL1}{dt} = -\frac{Vcc}{L1} - \frac{Vcf}{L2} + \frac{Va}{L1}$$

$$L2\frac{dIL2}{dt} + Vcf = 0$$

$$\frac{dIL2}{dt} = -\frac{Vcf}{L2}$$

$$CC\frac{dVcc}{dt} - IL1 = 0$$

$$\frac{dVcc}{dt} = \frac{IL1}{CC}$$

$$Cf\frac{dVcf}{dt} - IL1 - IL2 + \frac{Vcf}{R} = 0$$

$$\frac{dVcf}{dt} = -\frac{Vcf}{R*Cf} + \frac{IL1}{Cf} + \frac{IL2}{Cf}$$

$$\begin{bmatrix} \frac{dIL1}{dt} \\ \frac{dIL2}{dt} \\ \frac{dVc}{dt} \\ \frac{dVcf}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L2} & 0 \\ 0 & -\frac{1}{CC} & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{Rcf} \end{bmatrix} \begin{bmatrix} IL1 \\ IL2 \\ Vcc \\ Vcf \end{bmatrix} + \begin{bmatrix} \frac{1}{L1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [Va]$$

$$A1 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & \frac{1}{L2} & 0 \\ 0 & -\frac{1}{CC} & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{Rcf} \end{bmatrix}$$

$$B1 = \begin{bmatrix} \frac{1}{L1} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

When MOSFET OFF

$$\begin{bmatrix} \frac{dIL1}{dt} \\ \frac{dIL2}{dt} \\ \frac{dVc}{dt} \\ \frac{dVcf}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\frac{1}{L1} & -\frac{1}{L1} \\ 0 & 0 & 0 & -\frac{1}{L2} \\ \frac{1}{CC} & 0 & 0 & 0 \\ \frac{1}{CC} & \frac{1}{Cf} & 0 & -\frac{1}{Rcf} \end{bmatrix} \begin{bmatrix} IL1 \\ IL2 \\ Vcc \\ Vcf \end{bmatrix} + \begin{bmatrix} \frac{1}{L1} \\ 0 \\ 0 \\ 0 \end{bmatrix} [Va]$$
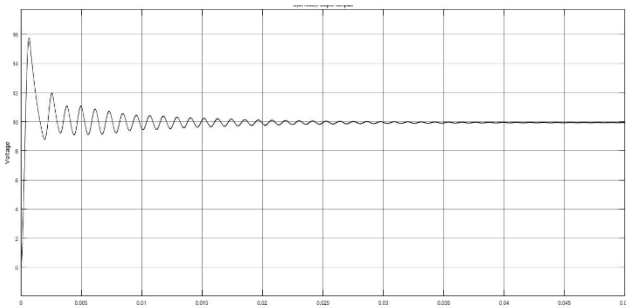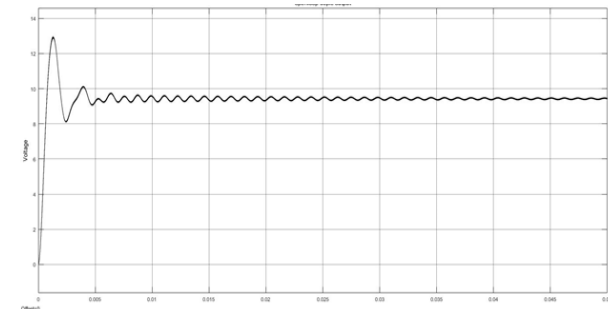
$$A2 = \begin{bmatrix} 0 & 0 & -\dfrac{1}{L1} & -\dfrac{1}{L1} \\ 0 & 0 & 0 & -\dfrac{1}{L2} \\ \dfrac{1}{CC} & 0 & 0 & 0 \\ \dfrac{1}{CC} & \dfrac{1}{Cf} & 0 & -\dfrac{1}{Rcf} \end{bmatrix}$$

$$B2 = \begin{bmatrix} \dfrac{1}{L1} \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

$$Vb = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} IL1 \\ IL2 \\ Vcc \\ Vcf \end{bmatrix}$$

$$C = \begin{bmatrix} 0 & 0 & 0 & 1 \end{bmatrix}$$

Input output voltage relationship can be describe as

$$\frac{Vb}{Va} = \frac{A1S^2 + A2}{A3S^4 + A4S^3 + A5S^2 + A6S + A7}$$

$$A1 = L2 * CC * R(1 - D)$$

$$A2 = RD(1 - D)$$

$$A3 = L1 * L2 * CC * Cf * R$$

$$A4 = L1 * L2 * CC$$

$$A5 = R(L1 * CC(1 - D)^2 + L2Cf(1 - D)^2 + L1 * Cf * D^2 + L2 * CC * (1 - D)^2)$$

$$A6 = L1 * D^2 + L2 * (1 - D)^2$$

$$A7 = R * (1 - D)^2$$

$$\frac{Vb}{Va}(S)$$
$$= \frac{4.1573e - 8 * S^2 + 1.338}{4.3553e - 15S^4 + 2.8805e - 12S^3 + 0.0001201379S^2 + 8.1217e - 5S + 0.79366}$$

For better transient and steady state response, a feedback path is given to the system. Here PI controller use for better transient and steady state operation. Output of the Closed loop system changed by changing the reference signal. Closed loop Matlab Simulink diagram shown in the figure with waveform.
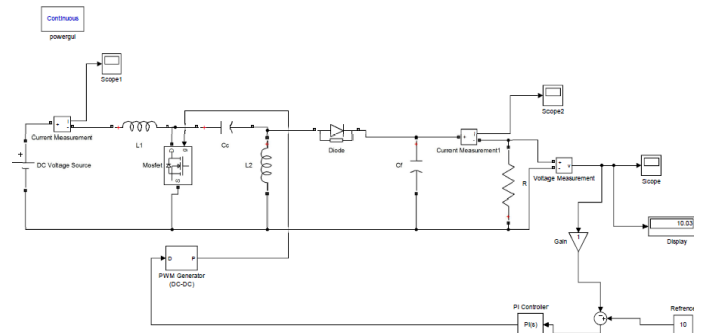

Fig.9. Matlab Simulink model of closed loop Sepic Converter
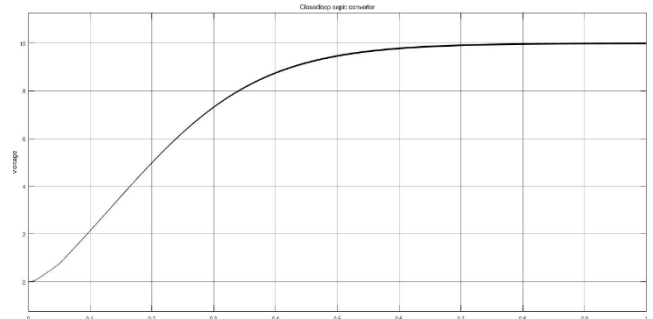

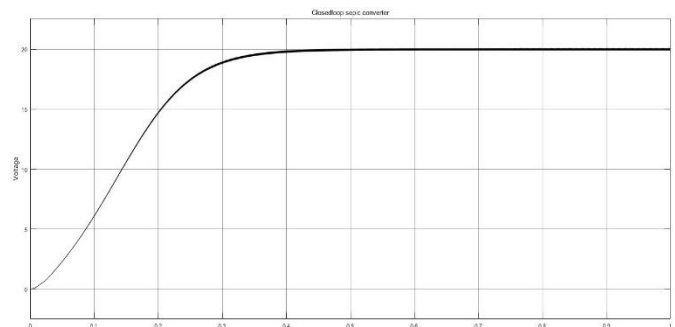Fig. 10. Closed loop Sepic Converter output Voltage when reference set to 10V

Fig. 11. Closed loop Sepic Converter output Voltage when reference set to 20V

Table 1. Required Parameters for designing of Sepic Converter		
Sr. No.	Parameter	Value
1	Va	6V
2	Inductor L1	151.2μH
3	Inductor L2	151.2μH
4	Coupling Capacitor	126μF
5	Filter Capacitor	252μF
6	Resistor	6Ω
7	Kp	0
8	Ki	0.2301

IV. CONCLUSION

All the specification and values of passive components for designing of a Sepic was determined. Matlab simulation using calculated parameters was performed in open loop and closed loop and corresponding waveforms were obtained. From simulation we observed that the output of closed loop system gives more accurate result than open loop system. Close loop System can use for input variation system. All required values of parameter are give in above table1. to operate Open loop Sepic converter as a buck converter duty cycle should be less than 50% and to operate as a boost converter duty cycle should be more than 50%.

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