Bilgisayar Sistemlerinde SEPIC Dönüştürücü Uygulaması ve Benzetim Çalışması

Araştırma Makalesi/Research Article

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(Geliş/Received:14.03.2019; Kabul/Accepted:28.03.2019)
DOI: 10.17671/gazibtd.540127

Özet— Bu çalışmada, bilgisayar sistemlerinde enerji kaynağı olarak kullanılan Tek Uçlu Primer İndüktör Çevirici (SEPIC) teknolojisinin analiz ve benzetim çalışması üzerinde durulmuştur. Bilgisayar sistemlerinde, bu dönüştürücülerin çok önemli bir yeri vardır ve yaygın olarak kullanılmaktadır. Bu sistemlerde gerilimi yükseltmek veya düşürmek için farklı tip devre topolojileri mevcuttur (Buck, Boost, Cuk vb.). Buck dönüştürücü sadece gerilimi düşürebilirken, Boost dönüştürücü gerilimi artırmaktadır. Cuk ve SEPIC her iki işlemde de kullanılabilmektedir. Buck, Boost ve Cuk dönüştürücü bileşenleri üzerindeki büyük miktarda elektriksel stres gibi durumlar ana kartı besleyen güç kaynaklarının aşırı ısınmasına neden olmaktadır. Ayrıca bu dönüştürücülerden negatif doğrultulmuş çıkış gerilimi elde edilmektedir. Bu problemler SEPIC dönüştürücülerde görülmemekle birlikte yüksek verimlilikle geniş çalışma imkânı sağlamaktadırlar. Anahtarlama elemanının geçit sinyalinin kontrol edilmesiyle, SEPIC dönüştürücüsünün pozitif doğrultulduğu şekliyle istenen çıkış gerilimi elde edilebilmektedir. Bu çalışma, diğer yöntemlerle kıyaslandığında iyi bir statik ve dinamik performansı sağlayabilen PI kontrolcüsünün geliştirilmesini hedeflemiştir. SEPIC dönüştürücüsünün benzetim çalışması Matlab/Simulink yazılımı kullanılarak yapılmıştır.

Anahtar Kelimeler— Sepic dönüştürücü, PI kontrol, Matlab Simulink, Bilgisayar sistemleri

The Simulation and Implementation of SEPIC Converter for Computer Systems

Abstract— In this study, the analysis and simulation studies on Single Ended Primary Inductor Converter (SEPIC) technology used as a energy source in computer systems are proposed. In computer systems, these converters are inevitable and used widely. To step up or step down voltage, different type circuit topologies are available (Buck, Boost, Cuk etc.). While buck converter can only decrease the voltage, boost converter steps up the voltage. Cuk and SEPIC can be used both process. Some issues like large amounts of electrical stress on the buck, boost and Cuk converter components, the main board power supplies can be overheating. Also negative regulated output voltage is obtained in these converters. These problems are not seen in SEPIC converters. Also they provide to wide operation with high efficiency. By controlling of the gate signal of switching devices, desired output voltage is obtained as positive regulated in SEPIC converter. This study proposed a development of PI control method that provides the proper dynamic and static performance compared to other methods. The simulation and implementation of SEPIC converter is simulated in Matlab/Simulink software.

Keywords— Sepic converter, PI control, Matlab Simulink, Computer systems

1. INTRODUCTION

In computer systems, some applications of converters only need to step-up or step-down the source voltage. It is important to simply the usage of corresponding converters. But, sometimes the proposed output voltage will be in the scope of input source. Thus, DC to DC converter technology is developing rapidly.

Single Ended Primary Inductor Converter (SEPIC) is interfacing with several storage devices and power sources that are used widely in nowadays. An independent power converter as SEPIC is used for each of the energy sources, common lower or higher DC bus voltage to connect with each multiple resources. The SEPIC converter regulates the dc voltage to be adjusted to maintain a constant and stable output voltage. This study deals with the importance of dc to dc and SEPIC converters.

The study of Venkatanarayanan and coworkers analyze and design of PI controller using SEPIC that is to start of DC to DC converter. Their study proposes a development of PI controller that is capable of providing the dynamic and static performance compared to PID control method [2].

The study of Anbukumar Kavitha and Govindarajan Uma, the analysis of confusion in a current mode controlled DC to DC SEPIC converter has been analysed. In this study, SEPIC converter is operated in current mode control with continuous conduction mode. The PI control algorithm is implemented to this converter. The reference current of PI controller is considered and varied to control the converter [3].

The study of Reeto Jose and their team is compared the different SEPIC converters. These are multi resonant, conventional and new resonant SEPIC converter. They have obtained the new resonant SEPIC converter has small size, higher efficiency, and better transient performance. It operates at fixed duty ratio and frequency. It eliminates the need of bulk inductor and reduces the component numbers. [4]

Jaw-Kuen Shiau and other sources study the different topologies of converters. They focus on the application of a converter simulation model using maximum power point tracking (MPPT) of solar power that includes different buck boost converters; including Zeta, SEPIC and 4 switch buck boost DC to DC converters [5-7].

2. THEORY AND PRINCIPLE OF SEPIC CONVERTER

2.1. The Operation of Converter

The single ended primary inductor converter (SEPIC) is a circuit of DC to DC converter. As differ from other DC to DC converters, its output can be greater than, equal or less than to its input. By the controlling of the Mosfet duty cycle, desired DC output voltage can be obtained. Also it has positive regulated output voltage for the given input voltage. The converter diagram of the converter is shown in Figure 1. In topology, the coupling capacitor provides isolation between output and input [5, 8].

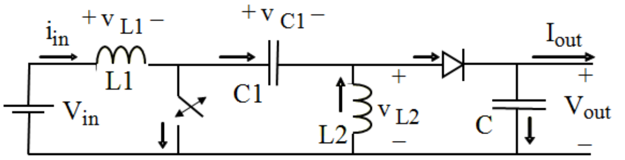


Figure 1. Converter diagram of SEPIC topology

2.2. Continuous Conduction Mode (CCM)

The converter is to be in continuous conduction mode, if the current through the inductor L_1 doesn't falls to zero state. During steady-state condition, the average voltage value of capacitor C_1 is equal to input voltage. The direct current is blocked by the capacitor C_1, so I_1(avg) is equal to zero which is average current through capacitor C_1. In this condition, the only source of load current is inductor L_2. It means average load current is equal to average current of inductor L_2 and it is independent from input voltage. From the Kirchhoff's Law, the following equation can be written:.

$$V_{in} = V_{L1} + V_{c1} + V_{L2} \quad (1)$$

$$V_{in} = V_{c1} \text{ (in steady-condition)} \quad (2)$$

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

As the magnitude of inductor voltages is equal to each other, ripple currents of inductors will be equal. Looking at average diode current is written as follows:

$$I_{D1} = I_{L1} - I_{L2} \quad (4)$$

When the Mosfet is in on state, the currents I_{L1} and I_{L2} (in negative direction) increases. In this state, we can say that the Mosfet is short circuit, so instantaneous voltage over capacitor Cs is approximately Vin and instantaneous voltage over inductor L_2 is $(-V_{in})$. During this cycle capacitor C_1 supplies the energy to the inductor L_2.

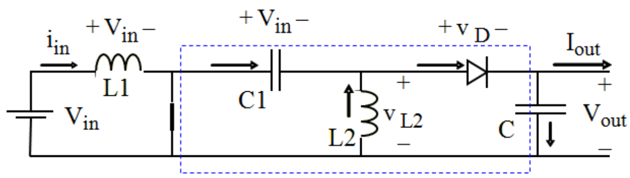


Figure 2. Circuit Diagram of SEPIC On State (CCM)

During the Mosfet is in off state, the Mosfet is open circuit and diode D_1 is forward biased, so instantaneous current of I_{L1} and I_{C1} is equal to each other. And diode current defined as follows:

$$I_{D1} = I_{C1} - I_{L2} \quad (5)$$

During this cycle inductor L_1 charges the capacitor Cs and inductor L_2 provide load current. Therefore, the buck-boost capabilities of circuit are determined with the capacitor C_1 and inductor L_2. Structure of inductor L_1 and

Mosfet is similar with boost converter; it provides output voltage is higher than input voltage. The output voltage is written as follows:

$$V_{out} = V_{Mosfet} - V_{in} \tag{6}$$

The Mosfet voltage is determined with duty cycle of switching gate signal. When Mosfet voltage is higher than double of input voltage, the circuit behaves as boost converter. If the V_{Mosfet} is less than double of input voltage, Sepic converter works as buck converter [9, 10].

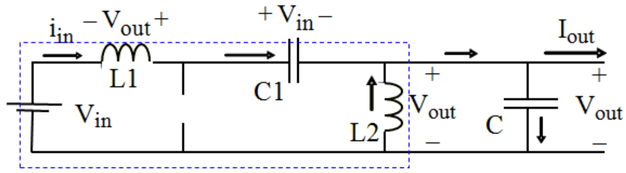


Figure 3. Circuit Diagram of SEPIC Off State (CCM)

2.3. Expected Waveform

Drain to source voltage of Mosfet is called as the voltage across Mosfet voltage. The gate signal of Mosfet is driven with PWM signal. Mosfet is working as switching device in circuit, so drain to source voltage is zero on state cycle. When it turns off, the magnitude of voltage V_{in} + V_{out} is seen over Mosfet.

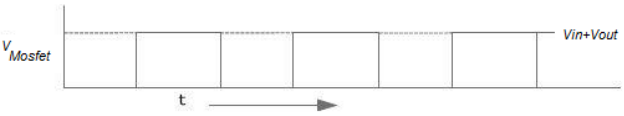


Figure 4. Drain-Source voltage across Mosfet

During on state cycle, the inductor L_1 current and inductor L_2 current flows through Mosfet and no current flows in off state cycle.

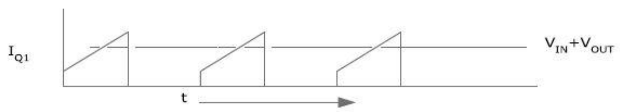


Figure 5. Current Through Mosfet

The other switching device in SEPIC is diode D_1. In this circuit it works in the opposite case of Mosfet. In other words, when the Mosfet turns off, the diode is conducting. During this cycle, the inductor L_1 current and inductor L_2 current flows through diode D_1. When the Mosfet turns on, diode is not conducting.

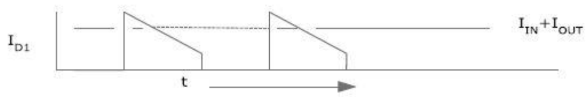


Figure 6. Current Through Diode

Coupling capacitor is charged by inductor L_1 during off cycle of Mosfet and then recharge over inductor L_2 during on state.

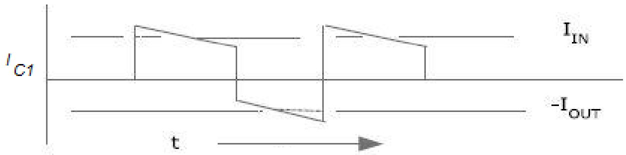


Figure 7. Current through coupling capacitor

When Mosfet turns on, the current through inductor L_1 is increasing to a certain value until Mosfet turn off. When Mosfet turns off, inductor L_1 is discharging to coupling capacitor and current start to decreasing. Similar case occurs in inductor L_2 with charging and discharging operation.

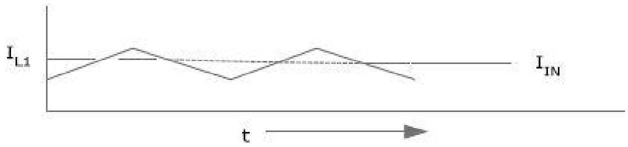


Figure 8. Current through inductor L_1

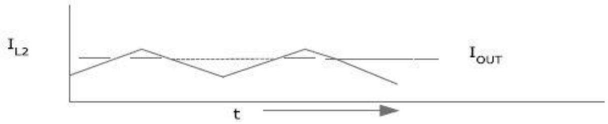


Figure 9. Current through inductor L_2

3. DESIGN OF SEPIC CONVERTER

The SEPIC converters can be used in many applications for charging batteries, supplying computer main boards, and SMPS, etc. This DC/DC converter is designed that supply constant 12 Vdc voltage at 500 mA current from an input voltage ranging from 9V to 15V. Desired the other specification is determined as follows:

Output ripple voltage = 0.2% of the output voltage

Output ripple current = 30% of the load current

Switching frequency = 330 kHz.

3.1. Duty Cycle Calculation

In SEPIC converters the range of duty cycle is determined with the voltage range of the input voltage. Output voltage/Duty cycle equation of ideal SEPIC converter is given by

$$V_{out} = \frac{D.V_{in}}{1-D} \tag{7}$$

Also it depends on parasitic elements in the circuits such as diode voltage drop. This make the equation;

$$V_{out} + V_D = \frac{DV_{in}}{1-D} \tag{8}$$

While minimum duty cycle occurs at maximum voltage, maximum duty cycle occurs at minimum voltage.

$$D_{\min} = \frac{V_{out} + V_D}{V_{out} + V_{in(\max)} + V_D} \tag{9}$$

$$D_{\max} = \frac{V_{out} + V_D}{V_{out} + V_{in(\min)} + V_D} \tag{10}$$

3.2. *Filter Design using Ripple Specification*

For the calculation of inductance value; the ripple current at minimum input voltage is allowed approximately 30% of maximum input current. The inductor ripple current is

$$\Delta I_L = I_{in.} 30\% = \frac{V_{out} . I_{out}}{V_{in(\min)}} .30\% \tag{11}$$

Inductance L_1 and L_2 is calculated as;

$$L_1 = L_2 = L = \frac{V_{in(\min)}}{\Delta I_L \cdot f_{sw}} D_{\max} \tag{12}$$

The peak current for inductor L1

$$I_{L1peak} = I_{in}(1 + \frac{\Delta I_L}{2}) = I_{out} \frac{(V_{out} + V_D)}{V_{in(\min)}} (1 + \frac{30\%}{2}) \tag{13}$$

The peak current for inductor L_2 is;

$$I_{L_{2peak}} = I_{out}(1 + \frac{30\%}{2}) \tag{14}$$

The selection of the coupling capacitor is related with RMS current and is given by;

$$I_{c1rms} = Iout \sqrt{\frac{(V_{out} + V_D)}{V_{in(\min)}}} \tag{15}$$

The voltage rating of the SEPIC capacitor is determined according to the maximum input voltage. The peak to peak ripple voltage is given by;

$$\Delta V_{C1} = \frac{I_{out} D_{\max}}{C_1 \cdot f_{sw}} \tag{16}$$

During Mosfet on state, output capacitor supply energy to the load and capacitor sees large ripple currents, so the output capacitor have to be capable of maximum output RMS current [11];

$$I_{out(rms)} = Iout \sqrt{\frac{(V_{out} + V_D)}{V_{in(\min)}}} \tag{17}$$

For the calculation of capacitance, it is assumed that half of output voltage ripple is occasioned by ESR, the other half is occasioned by the capacitance. Thus the following equations can be written:

$$ESR \le \frac{V_{ripple} .0,5}{I_{L1peak} + I_{L2peak}} \tag{18}$$

$$C_2 \ge \frac{I_{out} D_{\max}}{V_{ripple} \cdot f_{sw}} \tag{19}$$

Some criteria's are taken into account when selection of Mosfet.

- The peak Mosfet voltage is given by;

$$V_{Mosfet(\max)} = V_{out} + V_{in(\max)} \tag{20}$$

- The peak Mosfet current is given by,

$$I_{Mosfet(\max)} = I_{L1peak} + I_{L2peak} \tag{21}$$

- The rms current of the Mosfet is given by;

$$I_{Mosfet(rms)} = I_{out} \sqrt{\frac{(V_{out} + V_{in(\min)} + V_D)(V_{out} + V_D)}{V_{in(\min)}^2}} \tag{22}$$

Power dissipation over Mosfet is calculated as;

$$P_{Mosfet} = I_{Mosfet(rms)}^2 R_{DS(on)} . D_{\max} (V_{out} + V_{in(\min)}) I_{Mosfet(\max)} \frac{Q_{GD} \cdot f_{sw}}{I_G}$$

where, $R_{DS(on)}$, The on resistance, Q_{GD}, Gate-Drain charge, I_G, Gate Drive current

These variables can be obtained from the Mosfet datasheet. In SEPIC converter, the maximum current that is passed into the diode is equal to the maximum current through Mosfet. The other parameter for diode selection is maximum reverse voltage that is given by;

$$V_{RD1} = V_{out} + V_{in(\max)} \tag{23}$$

Table 1 shows the list of design calculation used in the SEPIC converter.

Table1. The design specifications of SEPIC circuit

Symbol	**Description**	**Calculated**
$Dmax$	Maximum Duty	*58.53*
$Dmin$	Minimum Duty	*45.85*
L1	Inductor	*7.9807e-05 H*
L2	Inductor	*7.9807e-05 H*
C1	Capacitor	*4.4337e-05 F*
C2	Capacitor	*8.8675e-05 F*
$IL1(peak)$	Peak Current L1	*0.8114 A*
$IL2(peak)$	Peak Current L2	*0.575 A*
$IQ1(max)$	Max Current Mosfet	*1.3864 A*
$IQ1(rms)$	RMS Current Mosfet	*0.9223 A*
$PQ1$	Power Loss Mosfet	*0.08276 W*
$VRD1$	Reverse Voltage Diode	*27 V*

4. SIMULATION RESULTS

4.1. Open Loop Simulation Results

Simulation of circuit is implemented in Matlab Simulink, given diagram in below is used for the open loop simulations.

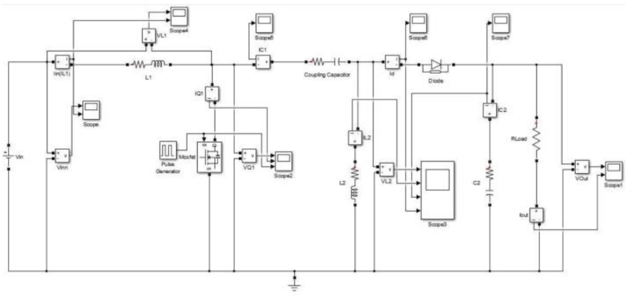


Figure 10. Open Loop Simulation Circuit in Matlab/Simulink Software

The results of current and voltage of Mosfet, current of diode are obtained in maximum duty cycle. The results are shown in Figure 11.

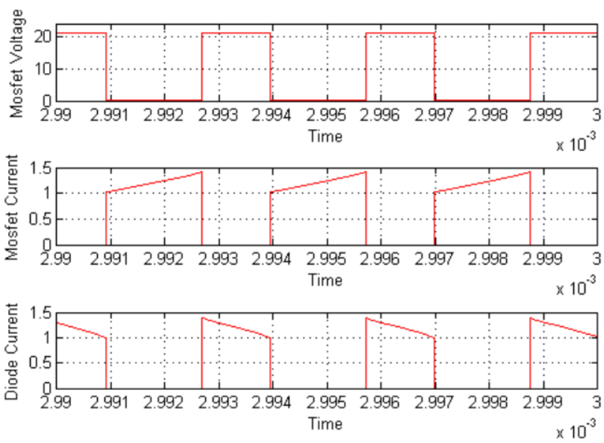
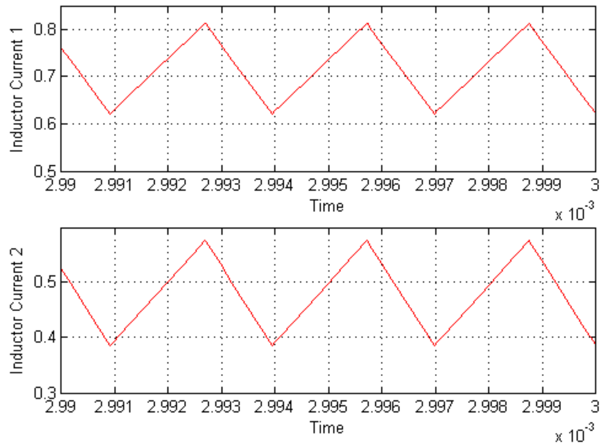
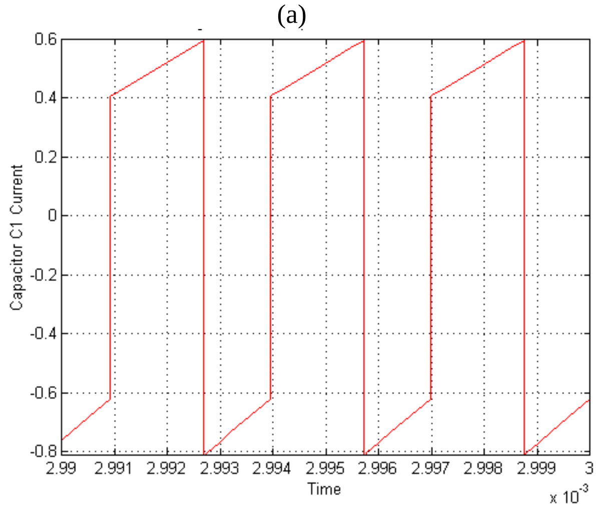


Figure 11. The waveforms of Mosfet current, voltage and diode current

At the maximum duty cycle, the waveform of capacitor C_1 current and inductor L_1, L_2 currents are shown in Figure 12.



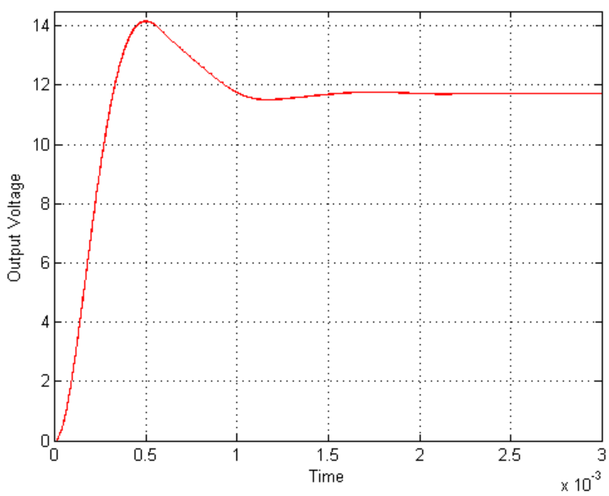
(a)



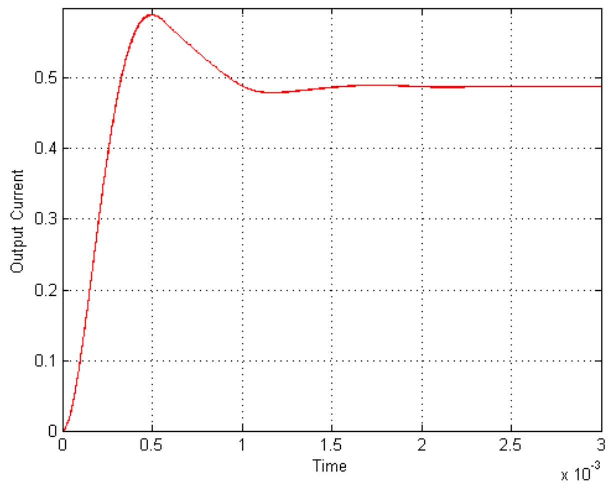
(b)

Figure 12. The waveforms of (a) I_{L1} and I_{L2} currents, (b) C_1current

The output voltage and current of the SEPIC converter is given in Figure 13 at maximum duty cycle.



(a)



(b)

Figure 13. The waveforms of voltage and current for open loop control (a) output voltage, (b) output current

4.2 Close Loop Simulation Results

To regulate the output voltage, PI controller is applied to converter. The results are simulated in discrete solver type. The PI controller compares the output voltage with the desired output voltage to obtain error. The output of PI controller is compared with the triangular wave and the duty cycle of the Mosfet gate pulse is obtained. With this controller, the output voltage is stable even though changing of the input voltage.

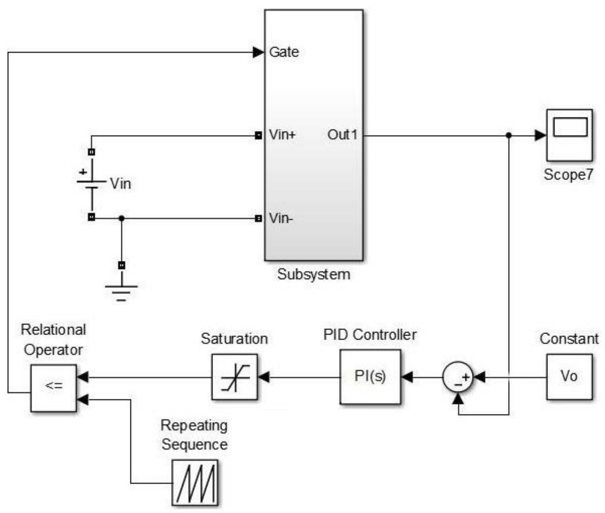
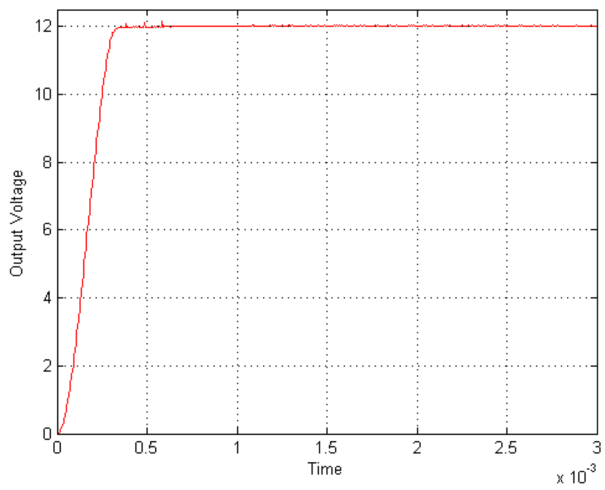
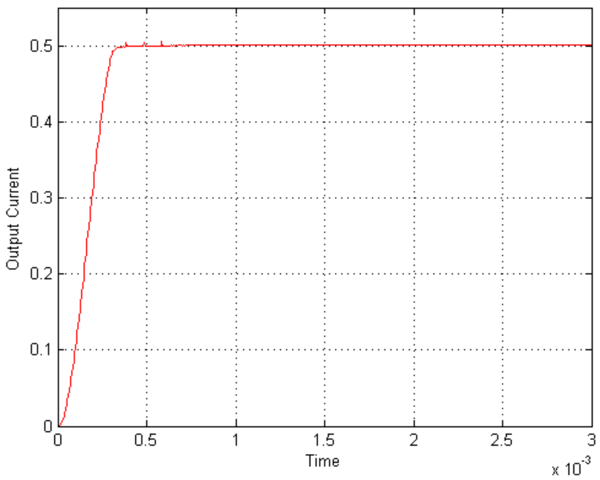


Figure 14. Closed Loop Simulation Circuit

The waveform of output current and voltage are shown in following Figure 15. It shows that the output is constant and doesn’t change the variation of conditions.



(a)



(b)

Figure 15. The waveforms of voltage and current for closed loop control (a) output voltage, (b) output current

CONCLUSION

According to design the specification of SEPIC converter, all components were determined in SEPIC converter circuit that was simulated in Matlab/Simulink Software. Simulations were performed in both open loop and close loop control algorithm. Expected waveforms in Section 2 are verified with the simulations results. Also desired specification was provided with designed SEPIC topology. The circuit was operated as boost converter with maximum duty cycle, and then was operated as buck converter with minimum duty cycle and it was observed that the output voltage was constant 12V that is supplies the loads of computer hardware. For closed loop simulations, the classical PI controller added to the circuit. Because of computer systems need robust and reliability converters to supply the loads. Thus, when it compared with open loop simulations, it was observed that the more accurate results were obtained with closed loop system.

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