DC-DC BUCK-BOOST AND SEPIC CONVERTERS TO DRIVE LED LIGHTS

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ABSTRACT
LEDs are current controlled device and have low dynamic resistance. To regulate current across LEDs, DC-DC Converters are used. These drivers control the power transfer from source to LEDs and hence control the brightness. This paper presents a comparative study between dc-dc buck-boost converter and SEPIC converter to drive an LED array. SEPIC converter which is a fourth-order converter provides non inverting output voltage as compared to Buck-Boost converter. Furthermore, it allows low ripples in the inductor current. Modeling of SEPIC and Buck-Boost converter with Led modeled as resistive load is also presented. A PWM control scheme is implemented to provide proper dimming control as well as to distinguish the behavior of drivers on the basis of its controlling performance. It is observed that to provide better dimming, it is advantageous to use SEPIC converter as compared to Buck-Boost converter. In order to validate the comparative analysis, simulation results are carried out in MATLAB SIMULINK.

KEYWORDS: *Buck-Boost Converter, SEPIC Converter, Light Emitting Diode (LED), MATLAB/SIMULINK.*

I. INTRODUCTION

About 20% of electrical energy is demanded for lighting globally [1]-[2]. Incandescent lamp has been the first source of light used for lighting but in these lamps about 90% of electrical energy is wasted as heat and only 10% of electrical energy is used for lighting. To reduce this energy loss and to increase the energy saving the energy inefficient incandescent lamps are replaced by other lighting devices such as Light Emitting Diode (LED) lamps and compact fluorescent lamp (CFL) [3]-[4].
Due to enormous improvement in the technology of LEDs as compared to other conventional lighting technology, LEDs become able to replace these conventional light sources. LED provides numerous advantages such as long life, environmental friendly, less energy consumption, wide chromatic variety, high luminous efficacy etc [5]-[9] These advantages made led to be used in street lighting, traffic signs, vehicle lights, television backlight and other lighting applications[10]-[11]. I-V characteristics of LED show that this device is a current controlled device [12]-[13]. Any change in forward current of LED cause change in its luminous intensity [14]-[15]. To provide constant current to LEDs and to maintain luminous intensity stable LED drivers are used. These drivers' acts as power supply for the LEDs and provide stabilized current to LED [16]-[17]. Control the brightness of light in LED also offers the saving of electrical energy used for lighting to about 30%-40% and is known as dimming. Dimming is also used to maintain the lighting level as according to the need of human [18]. A single LED is not sufficient to produce sufficient amount of light because of their point source nature and current concentration; hence array of LEDs connected in series and parallel should be used [19].

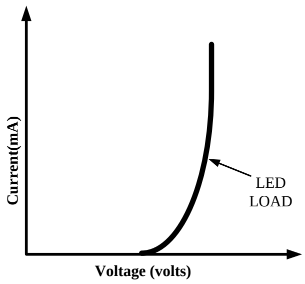


Figure 1. I-V characteristics of LED load.

The amount of light emitted by LED and chromaticity depends on the value of forward current. In analog dimming peak value of the DC current coincides with the average value of the current, so due to variation in the forward current, chromaticity problem arises. PWM dimming offers the effective solution to the problem of colour chromaticity. PWM current works at a frequency higher than 400 Hz and removes the problem of flickering [20]. The proper selection of driver as well as the control schemes is an efficient way to drive an LED array, since it affects its efficiency and accuracy.

In this paper, comparison of DC-DC Boost converter and DC-DC SEPIC converter with their parasitic elements in continuous conduction mode as LED driver to drive an array of LED lamps is presented. To validate the theoretical concept simulation is done using MATLAB/ SIMULINK environment. Rest of the paper is organized as follows: Modeling of LED lamps and dc-dc converters is presented in Section II and section III respectively. Section IV describes the results and discussion while conclusion is given in Section-V.

II. MODELLING OF LED LAMP

The current-voltage characteristic of LED lamp is given as in (1) as

$$I = m \times \exp(nv) \tag{1}$$

Where m and n are independent parameters. From (1), it is observed that small variation in the voltage V cause change in current by large amount; to limit this rise in current a resistance is always connected in series with it to protect it from damage.

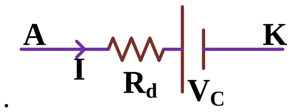


Figure 2. Equivalent circuit of LED.

Figure 2 shows the equivalent circuit of LED lamp, in which LED is equivalent to a voltage source consists a resistance in series with it. The forward voltage across LED load is given as

$$V_{AK} = I \times R_d + V_c$$

Where V_{AK} is the forward voltage drop of LED, R_d& V_C are the dynamic resistance and cut-in voltage if the LED respectively. It is not necessary that each LED of a same manufacturing unit has same I-V characteristics; it depends on the manufacturing process of the LED. The colour of light emitted from LED depends on the energy band gap of the material used [21].

III. MODELLING AND DESIGN OF DC-DC CONVERTERS

This section represents the modelling and state-space analysis of dc-dc converter. For the dc-dc converter in continuous-conduction mode (CCM), for a complete switching cycle due to switching action of MOSFET switch and, diode, two states are possible namely, Mode I: when switch SW is ON and diode D is OFF, Mode II: when switch is OFF and diode D is ON. The state space equations for the two states are given in (2) as [23]:

$$\left.\begin{aligned}\dot{x} &= A_i x + B_i u\\ y &= E_i x + F_i u\end{aligned}\right\} \quad (2)$$

Where $i = (1, 2)$ represents the number of modes of operation and the equations for the two mode are given in (3) & (4) as [22]-[23].

$A_1, A_2 \in R^{N\times N}, B_1, B_2 \in R^{N\times 1}, E_1, E2 \in R^{1\times N}, F \in R$.

For mode I,

$$\left.\begin{aligned}\dot{X} &= A_1 x + B_1 u + M_1 i_Z\\ Y &= E_1 x + F_1 u + J_1 i_Z\end{aligned}\right\} \quad (3)$$

For mode II,

$$\left.\begin{aligned}\dot{X} &= A_2 x + B_2 u + M_2 i_Z\\ Y &= E_2 x + F_2 u + J_2 i_Z\end{aligned}\right\} \quad (4)$$

where input vector u represents the input voltage v_g, output vector y represents the output voltage v_0, the current source i_z indicate the small change in load current and x represents the state vector, which is given in (5) as [25]

$$x = \begin{bmatrix} i_{L1} & i_{L2} & v_{C1} & v_{C2} \end{bmatrix}^T \quad (5)$$

To get information about the averaged behaviour of the SEPIC converter in CCM for one complete switching cycle of time interval T, duty cycle is introduced in (1)

$$\left.\begin{aligned}\dot{x} &= Ax + Bu\\ y &= Ex + Fu\end{aligned}\right\} \quad (6)$$

Using small ac perturbations which is represented by "~" in dc steady state quantities, (6) which is in non linear form is converted into linearized form

So, $x=X+\tilde{x}$, $y=Y+\tilde{y}$, $u=U+\tilde{u}$, $d=D+\tilde{d}$

Where upper case letters represents the dc value [26].

Using this perturbation, the steady state space equation can be written as [25]:

$$\left.\begin{aligned}\dot{X} &= AX + BU + Mi_z\\ Y &= EX + FU + Ji_z\end{aligned}\right\} \quad (7)$$

3.1 State-Space Model and Design of DC-DC Buck-Boost Converter

The circuit configuration of boost converter is shown in figure 3. The time domain analysis is used to determine the voltage gain of the converter which is given in (8) as [23]

$$\frac{V_0}{V_g} = \frac{-D}{1-D} \quad (8)$$

Assuming that the boost converter is operating in CCM mode, depending on the position of the switch two modes of operation are possible.

MODE I: In this mode Switch is in ON state and Diode remain OFF. Current i_L flows through the L and inductor stores energy. The dynamic equations for this mode are given in (9) as [23]

$$\left.\begin{aligned} L\frac{di_L(t)}{dt} &= V_g - r_L i_L \\ C\frac{dv_C}{dt} &= -\frac{v_C}{C\left(1+r_C\right)} \end{aligned}\right\} \quad (9)$$

MODE II: During this mode switch remains OFF and Diode is in ON state. Inductor L delivers its energy to the load R. The dynamic equations for this mode are given in (10) as [23]

$$\left.\begin{aligned} L\frac{di_L}{dt} &= -\left(v_C + r_L i_L + i_C r_C\right) \\ C\frac{dv_C}{dt} &= \left(\frac{r_C}{R(R+r_C)}\right) i_L - \frac{v_C}{(R+r_C)} \end{aligned}\right\} \quad (10)$$

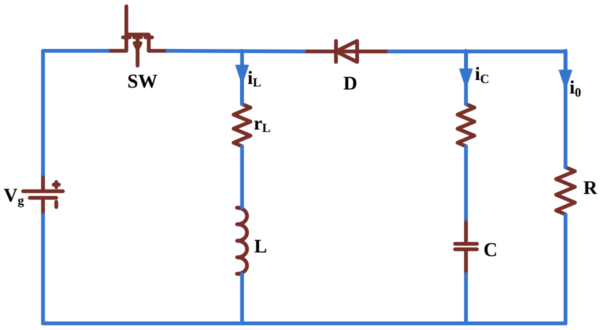


Figure 3. DC-DC buck-boost converter

The State transition matrix, input and output matrix for DC-DC boost Converter are given in (11) as [22]:

$$\left.\begin{aligned} A_1 &= \begin{bmatrix} -\frac{r_L}{L} & 0 \\ 0 & \frac{-1}{C(1+r_C)} \end{bmatrix}, A_2 = \begin{bmatrix} -\frac{r_L}{L} & -\frac{1}{L} \\ \frac{1}{C}\left(\frac{r_C}{R(R+r_C)} - 1\right) & \frac{-1}{C(R+r_C)} \end{bmatrix}, B_1 = \begin{bmatrix} 0 \\ 0 \end{bmatrix}, B_2 = \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} \\ E_1 &= \begin{bmatrix} 0 & \frac{R}{R+r_C} \end{bmatrix}, E_2 = \begin{bmatrix} -\frac{r_C}{R+r_C} & \frac{R}{R+r_C} \end{bmatrix}, F_1 = F_2 = [0] \end{aligned}\right\} \quad (11)$$

The equation which is used to calculate the value of inductor L and capacitor C is given in (12) as [25]

$$L = \frac{V_g \times DT}{\Delta i_L}, C = \frac{V_0 \times DT}{R \times \Delta v} \quad (12)$$

Where T is the switching period, Δi_L is the peak to peak ripple in current & Δv is the peak to peak ripple in voltage.

3.2 State-Space Model and Design of DC-DC SEPIC Converter

The circuit configuration of SEPIC converter is shown in figure 4.During mode I current in inductors L_1 and L_2 rises, L_1 stores energy form the input voltage source. In this mode capacitor C_1 and inductor L_2 are connected in parallel. The instantaneous voltage across C_1 is approximately equal to V_g, so the voltage across L_2 is approximately equal to $-V_g$. During mode 2, diode D gets forward biased, hence the same current flows through L1 and C_1. The current i_{L1} and i_{L2} flows through diode into the load get decreases during this mode. The voltage gain for the SEPIC converter is given is (13) as [26]

$$\frac{V_0}{V_g} = \frac{D}{1-D} \tag{13}$$

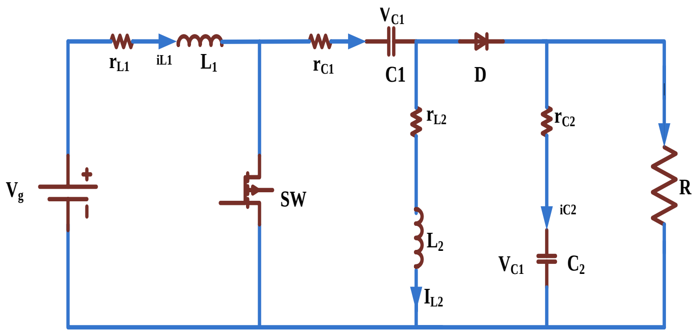


Figure 4. DC-DC SEPIC converter

The State transition matrix, input and output matrix for DC-DC SEPIC Converter are given in (14) as [22]

$$\left.\begin{aligned} A_1 &= \begin{bmatrix} \frac{-(r_{L1}+r_{SW})}{L_1} & \frac{-r_{Sw}}{L_1} & 0 & 0 \\ \frac{-r_{SW}}{L_2} & \frac{-(r_{SW}+r_{C1}+r_{L1})}{L_2} & \frac{1}{L_2} & 0 \\ 0 & \frac{-1}{c_1} & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{C_2(R+r_{C2})} \end{bmatrix}, A_2 = \begin{bmatrix} \frac{-(r_{L1}+r_{C1}+r_d+a)}{L_1} & \frac{-(r_d+a)}{L_1} & \frac{-1}{L_1} & \frac{-b}{L_1} \\ \frac{-(r_d+a)}{L_2} & \frac{-(r_{L2}+r_d+a)}{L_2} & 0 & \frac{-b}{L_2} \\ \frac{1}{c_1} & 0 & 0 & 0 \\ \frac{(R-a)}{RC_2} & \frac{(R-a)}{RC_2} & 0 & \frac{-b}{RC_2} \end{bmatrix}, \\ B_1 &= B_2 = \begin{bmatrix} \frac{1}{L_1} & 0 & 0 & 0 \end{bmatrix}^T, E_1 = \begin{bmatrix} 0 & 0 & 0 & \frac{R}{R+r\cdot C_2} \end{bmatrix} \quad E_2 = \begin{bmatrix} b\cdot r_{C2} & -b\cdot r_{C2} & 0 & b \end{bmatrix} \quad F_1 = F_2 = [0] \end{aligned}\right\} \tag{14}$$

Where $a = \frac{R \cdot r_{C2}}{R + r_{C2}}, b = \frac{R}{R + r_{C2}}$

The equations which are used to calculate the value of inductors L_1, L_2 and capacitors C_1, C_2 is given in (15) as [27]

$$L_1 = L_2 = \frac{V_g \times DT}{\Delta i_L}, C_1 = C_2 = \frac{D^2 \times V_g T}{(1-D) R \times \Delta v} \tag{15}$$

IV. RESULTS AND DISCUSSION

The Matlab/Simulink model of the buck-boost converter and SEPIC converter are shown in figure 5. For simplicity, LED load is replaced by the resistance. The switching frequency is maintained at 50 kHz for PWM generation. To validate the discussed control schemes, Simulation results have been shown using Table 1 & Table 2 in MATLAB/SIMULINK environment. The waveforms of the buck-boost converter and SEPIC converter for two different cases are shown to validate the comparison analysis. Two different cases which are used to display the result are: (i) for 25% step change in supply voltage i.e. from 9V to 15V at constant load R of 10Ω, (ii) When input supply and load remains constant i.e. V_g is maintained at 12V and load is of 10Ω. Figure 6 shows the simulated waveform for 25% step change in the source voltage for SEPIC converter, it is observed that the change in load voltage and current at 30% and 70% duty cycle is cancelled out in about 25 msec and 5 msec respectively.

Table 1. Circuit Parameters for SEPIC Converter

Circuit parameter	Value
V_g	9 V→15 V
L_1, r_{L1}	150 µH, 0.05 Ω
L_2, r_{L2}	180 µH, 0.05 Ω
C_1, r_{C1}	220 µF,0.02 Ω
C_2, r_{C2}	220 µF,0.02 Ω
R	10 Ω
f_S	50 kHz

Table 2. Circuit Parameters for Buck-Boost Converter

Circuit parameter	Value
V_g	9 V→15 V
L,,r_L	150 µH, 0.05 Ω
C,,r_C	220 µF,0.02 Ω
R	10 Ω
f_S	50 kHz

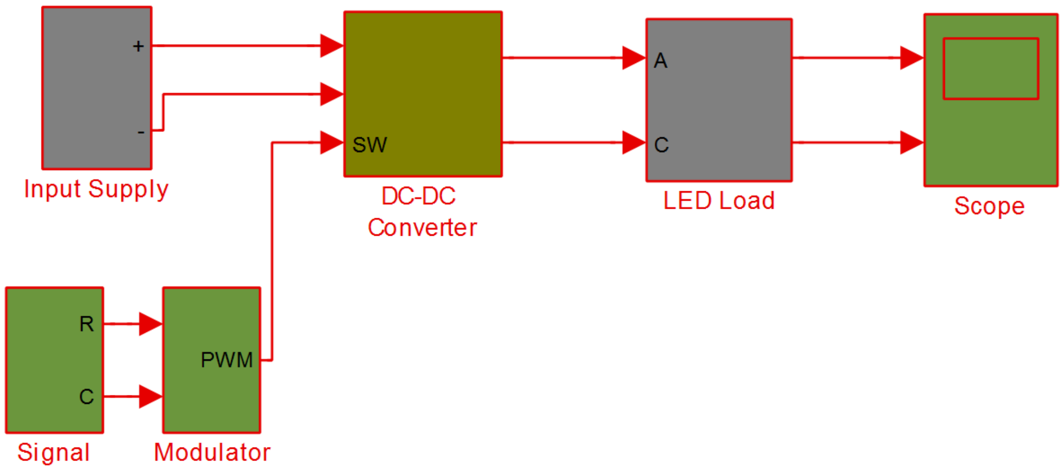
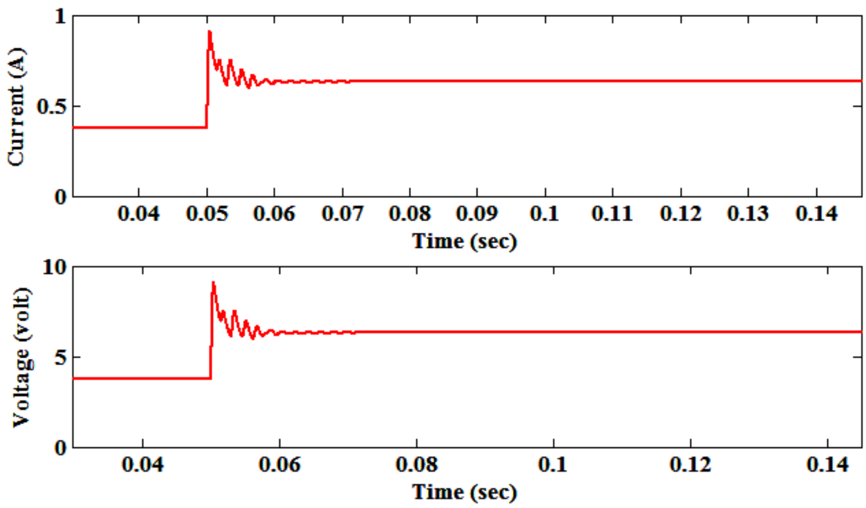
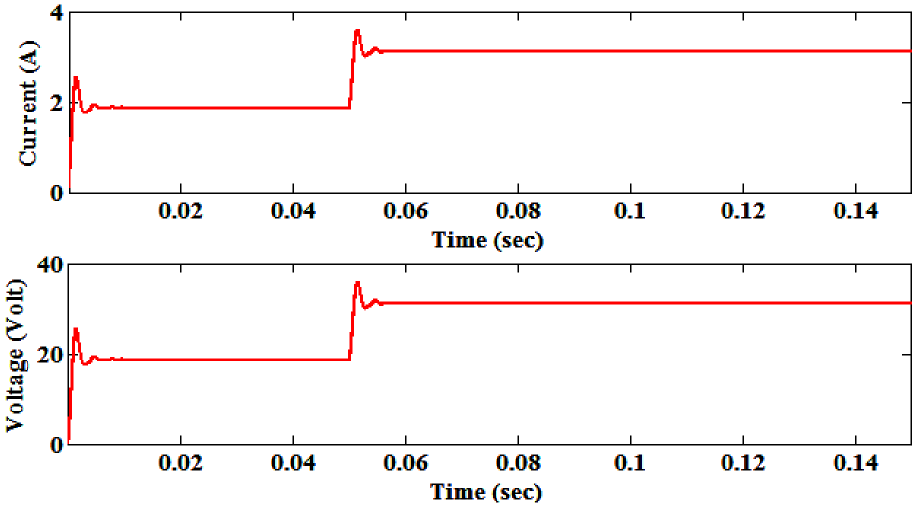


Figure 5. MATLAB-SIMULINK model of Buck-Boost/SEPIC Converter

Figure 7 shows the simulated results for the SEPIC converter at constant source voltage and at load of 10Ω at duty cycle of 30% and 70%. Figure 8 shows the simulated waveform for 25% step change in the source voltage for Buck-Boost converter, from figure 8 it is observed that the change in load voltage and current at 30% and 70% duty cycle is rejected in about 27 msec and 10 msec respectively.

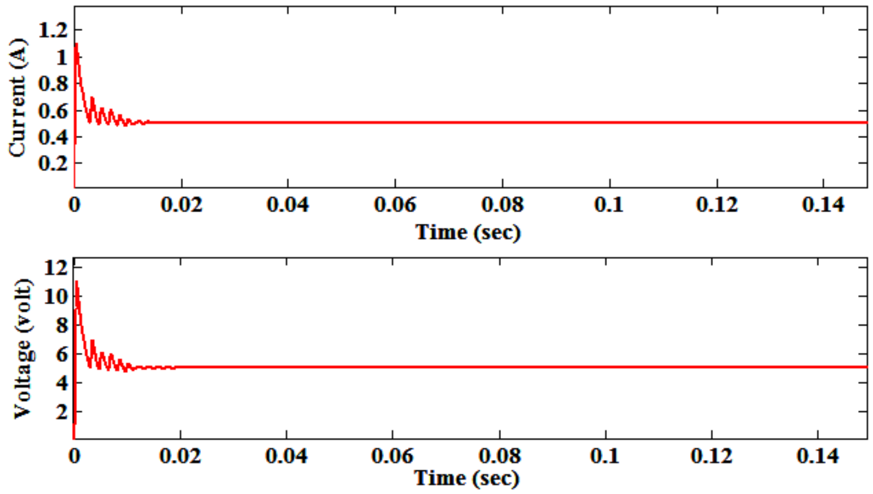


(a)

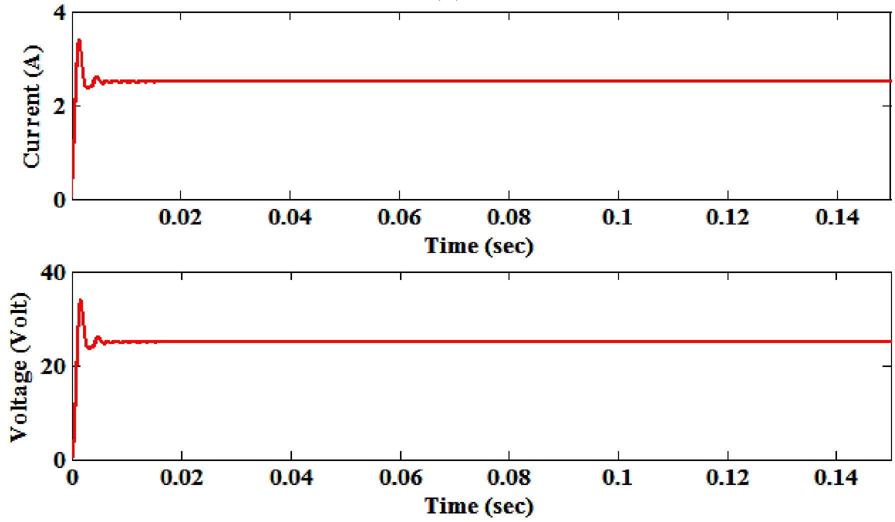


(b)

Figure 6. Dynamic response of current and voltage in SEPIC Converter at 30% and 70% duty cycle for V_g varies from 9V to 15V and Rat 10Ω.



(a)



(b)

Figure 7. Dynamic response of current and voltage in SEPIC Converter at 30% and 70% duty cycle for V_g at 12V and R at 10Ω.

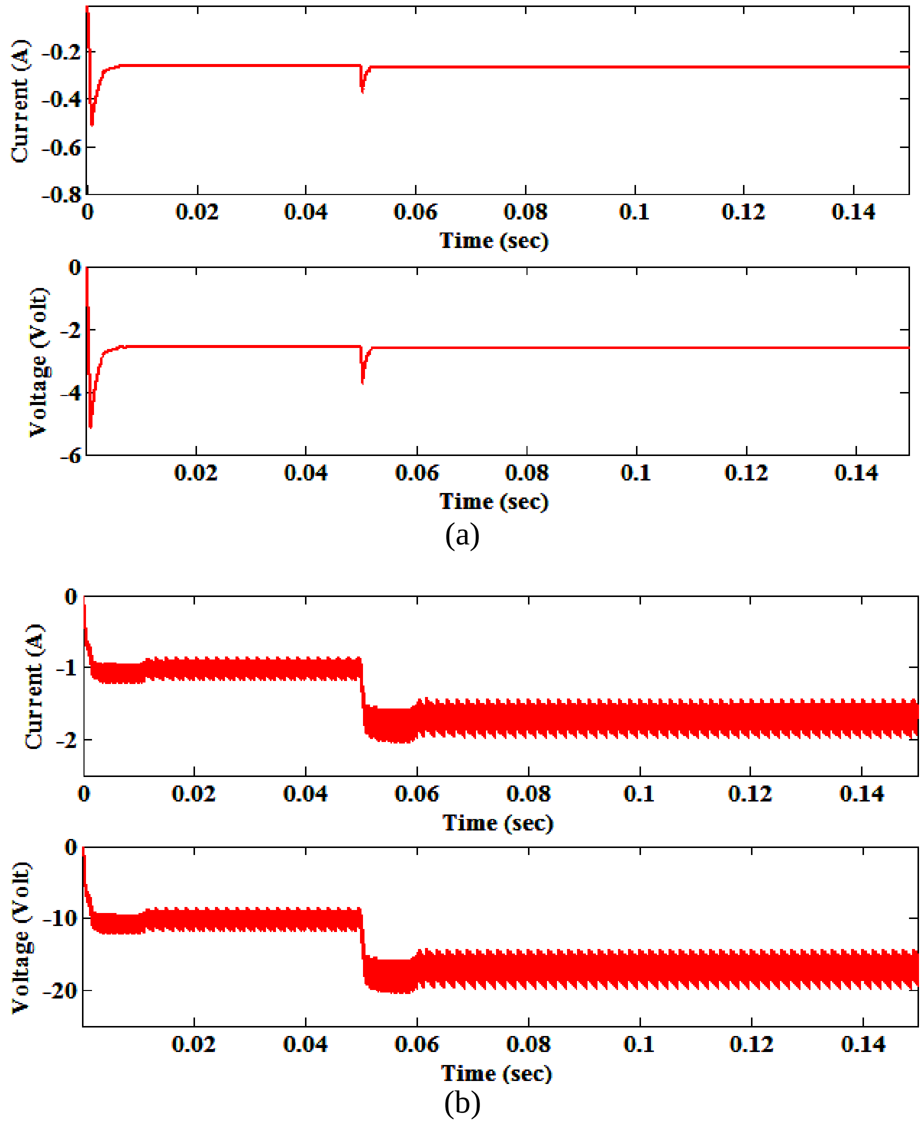
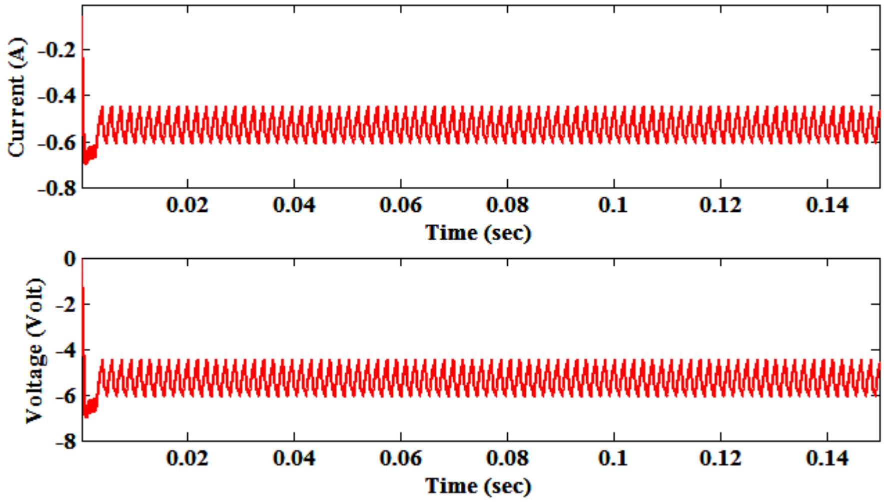
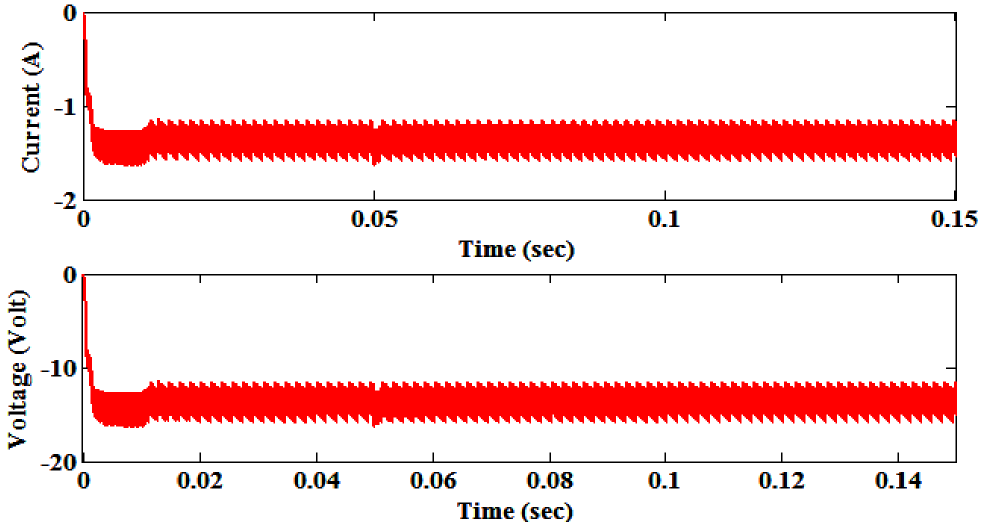


Figure 8. Dynamic response of current and voltage in Buck-Boost Converter at 30% and 70% duty cycle for V_g varies from 9V to 15V and R at 10Ω.



(a)



(b)

Figure 9. Dynamic response of current and voltage in Buck-Boost Converter at 30% and 70% duty cycle for V_g at 12V and R at 10Ω.

Form the simulated results, it is observed that Buck-Boost Converter provides inverted output voltage and SEPIC Converter provides non inverted output voltage. Also using SEPIC Converter as a driver for LED load provides less ripple in the current as compared to the Buck-Boost Converter. Because of these features it is advantageous to use SEPIC Converter as a driver for LED load.

V. CONCLUSION

The Comparative study of dc-dc SEPIC converter and Buck-Boost Converter as a LED driver to drive the LED array has been presented. The SEPIC converter as a LED driver provides an efficient approach to provide smooth dimming over wide range. The SEPIC Converter provides an additional advantage of low ripples in the input current and non inverting output voltage over Buck-Boost Converter. Since load is a LED array, effective use of energy is achieved, in addition with numerous advantages over other conventional lighting devices. Small-signal discrete-time model of dc-dc SEPIC converter and Buck-Boost converter is derived which is used to analyze the dynamic behaviour of driver circuit. The simulated results were shown to verify the theoretical predictions.

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