Designing of Modified SEPIC Converter for LED Lamp Driver

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***Abstract:*-Due to the recent advancement in the Light Emitting Diode (LED) technology, high brightness white LED becomes feasible in residential, industry and commercial applications to replace the incandescent bulbs, halogen bulbs, and even compact fluorescent light bulbs. In these offline applications, high power factor, and low harmonics are of primary importance.**

In this paper, we proposed a high power factor SEPIC converter for the high brightness. The harmonics of the input line current is reduced and power factor is high.

A current feedback loop is proposed to control the LED brightness. This circuit has the advantages of one stage of power conversion, no need to sense the input voltage, simple feedback control, and voltage step-up and down, high power factor and dimmable LED current.

LEDs plays a vital role in the industry and in our life. The SEPIC converter is to increase the efficiency of LEDs and get the better resolution than the other lighting application.

Keywords—harmonics, SEPIC, feedbackloop, conversion, resolution.

I. INTRODUCTION

A design of LED lamp driver using SEPIC converter will have the following section: Energy Source, Fixed DC conversion, Controller, Power distribution We use a DC supply in the circuit for the converter. If the supply is AC then this supply is fed in to the Bridge rectifier then we get a variable DC. For the ideal condition we use a Dc supply. In this case a current is constant.

DC bus section contains a SEPIC converter which converts a variable voltage available across supply to fixed DC bus voltage. This voltage is step downed using converter to supply different load. Controller is use for removing the variation from the output and we get a constant current across the load.

Power distribution section convert DC bus voltage was different voltage levels as per the need of other subsystem of any device.

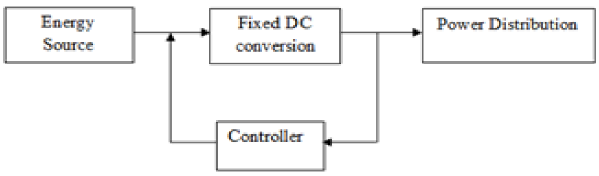

Fig. 1 General Structure of LED Driver using SEPIC converter.

II. CLASSIFICATION OF DC-DC CONVERTER

There are two types of regulated DC power supply- linear power supply and switched mode power supply. The linear power supply operates as an active resistance controlled circuit. In switch mode power supply, ac power is rectified to get a dc power and this dc power is chopped to regulate the output voltage by turning ON and OFF controlled silicon switches.

A DC to DC converter works by converting the voltage level of a direct current (DC) source to another level. It is simply a power converter used to provide standard, unregulated, regulated, high isolated or extra wide voltage output for various applications.

Basically two main types of converter are follows:

A. Non Inverting Converter

The output voltage is the same polarity as the input. These are basically three types,

1. BUCK Converter-The output voltage is lower than the input voltage
2. BOOST Converter- The output voltage is higher than the input voltage.
3. SEPIC Converter - The output voltage can be lower or higher than the input

B. Inverting Converter

The output voltage is of the opposite polarity as the input. These are basically two types,

1. CUK Converter-Output current is continuous
2. BUCK-BOOST Converter - The output voltage can be lower or higher than the input

III. SEPIC CONVERTER

Figure 3 shows a simple circuit diagram of a SEPIC converter, consisting of an input capacitor C_{IN}; an output capacitor C_{OUT}; coupled inductors L_{1a} and L_{1b}; an AC coupling capacitor C_P; a power FET Q_1; and a diode D_1. Capacitor C_P is charged to the input voltage, V_{IN}. When Q_1 is off, the voltage across L_{1b} must be V_{OUT}. Since C_{IN} is charged to V_{IN}, the voltage across Q_1 when Q_1 is off is $V_{IN} + V_{OUT}$, so the voltage across L_{1a} is V_{OUT}. When Q_1 is on, capacitor C_P, charged to V_{IN}, is connected in parallel with L_{1b}, so the voltage across L_{1b} is $-V_{IN}$.

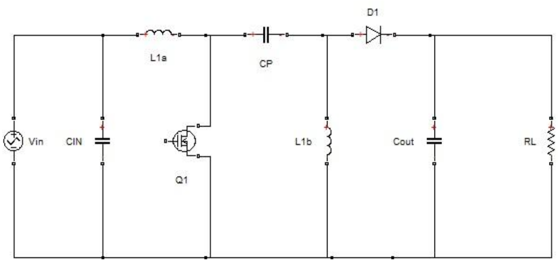

Fig 3 : SEPIC Converter

When Q_1 is on, energy is being stored in L_{1a} from the input and in L_{1b} from C_P. When Q_1 turns off, L_{1a}'s current continues to flow through C_P and D_1, and into C_{OUT} and the load. Both C_{OUT} and C_P get recharged so that they can provide the load current and charge L_{1b}, respectively, when Q_1 turns back on.

Advantage:-

1. Non – Inverted output.
2. Diode works as a reverse blocking mode.

Disadvantage:-

1. Circuit complexity is high.

TABLE-1

COMPARISON BETWEEN DC-DC CONVERTERS

CONVERTER	INDUCTOR POSITION	INPUT-OUTPUT ISOLATION	SWITCH VOLTAGE	OVER CURRENT CONTROL	EFFICI-ENCY	VOLTAGE RELATION
BUCK	BAD	DIFFICULT	V_O	NO	80%	$0 \le Out \le In$, $V_2 = DV_1$
BOOST	GOOD	DIFFICULT	V_O	NO	70%	$Out \ge In$, $V_2 = \frac{1}{1-D}V_1$
BUCK-BOOST	BAD	EASY	$V_O + V_{max}$	YES	78%	$Out \le 0$, $V_2 = -\frac{D}{1-D}V_1$
CUK	GOOD	EASY	$V_O + V_{max}$	YES	85%	Any inverted, $V_2 = -\frac{D}{1-D}V_1$
SEPIC	GOOD	EASY	$V_O + V_{max}$	YES	90%	Any, $V_2 = \frac{D}{1-D}V_1$

IV. LED CIRCUIT

LEDs come in all shapes and sizes, but the 3mm T-1 or 5mm T-1¾ are probably the most common.

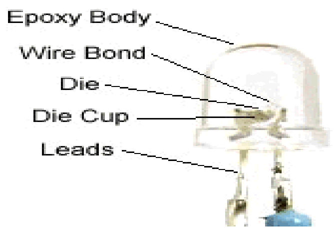

Fig 4(a): Circuit diagram of LED

As a rule of thumb, different color LEDs require different forward voltages to operate - red LEDs take the least, and as the color moves up the color spectrum toward blue, the voltage requirement increases. Just remember that the non-linear relationship between voltage and current means that Ohm's Law doesn't work for LEDs.

To keep the current down to a reasonable level, a series resistor must be included in the circuit.

The formula for calculating the value of the series resistor is:

$R_{series} = (V - V_f) / I_f$

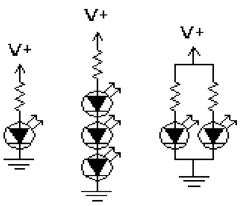

Fig4(b):Series resistor is connected with LED

Advantages of LEDs.:-

1. Extremely long life, c. 100 000 hours. When one LED fails there are many more for back-up.
2. Extreme robustness: as there are no glass components or filaments they are virtually insensitive to vibration and movement.
3. No need for an external reflector as a reflector is enclosed in the lamp casing to a predetermined beam width.
4. A modular construction, which can be chosen to provide any required shape or light output.

V. DIMMING AND FEEDBACK CONTROL

A. Dimming Method

There are two kinds of dimming for LED lighting. One is to control the LED average current, and the other is to control the lux of the LED lamp.

There are two methods,

1. Control the LED current by PWM
2. Change the reference of the control loop.

1). Control the LED current by PWM

In the PWM method, the LED current is controlled by a small power MOSFET, the duty ratio D of which varies for dimming. In dimming circuits, a low power MOSFET is connected in series with the LED string. The MOSFET is controlled by the PWM of the dimming frequency *fd*. At *D/fd*, the LED conducts a constant current *Io*. So the tune of the color does not change with the brightness. At *(1-D)/fd*, LED current is turned off. The LED can be turned on and off very fast without any negative effect. The average of the LED current is *DIo*. Hence brightness is changed with *D*. This method is widely used in display applications.
2.Change the reference of the control loop.
The other is the so-called analog control, that is, to control the reference of the loop. By changes the reference signal, the LED current can be adjusted. In return, the brightness of LED is changed. Based on how the reference signal is adjusted, there are further two methods.

i. DC dimming method
ii. AC dimming method

i) DC Dimming Method.

In A DC Dimming Method, The Reference Is Obtained From A Constant 5V Source And Is Changed Using A Variable Resistor Or Digital Controlled Resistor.

*ii) AC Dimming Method***.**

In This Method, The Reference Is In Proportion To The Input Ac Average Voltage. Therefore, The Widely Used Traditional Dimmer Can Be Used In Combination To Adjust The LED Current. Both Of These Methods Regulate The LED Current To Adjust The LED Brightness.

VI. MODELING OF CONVERTER

Voltage across the LEDs varies depending upon the isolation, temperature at which they are operating. This voltage can vary over a wide range, we may need to step up or step down the voltage. This can be done using either BUCK-BOOST converter or SEPIC converter. SEPIC converter is chosen because its output voltage is of same sign as that of input. Connection diagram of system is as shown in Fig 6.

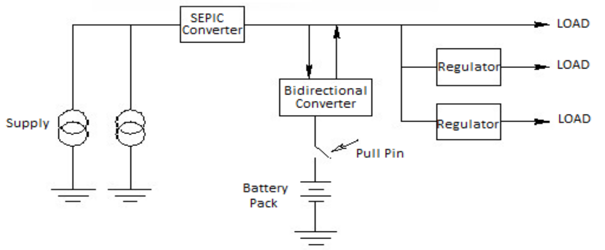

Fig 6: Block Diagram of the System.

VII. SEPIC CONVERTER MODELING

The single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. Unfortunately, the SEPIC topology is difficult to understand and requires two inductors, making the power-supply footprint quite large. The coupled inductor not only provides a smaller footprint but also, to get the same inductor ripple current, requires only half the inductance required for a SEPIC with two separate inductors. The LED Lamp driver proposed in Fig 7(a) relies on using the conventional SEPIC PFC converter shown in Fig 6. Operating it in DCM has the advantages of one single stage power conversion, high power factor, reduced component count and simple controller but the components' voltage stresses are high e.g. the switch has voltage stress of (V_{in} + V_o).

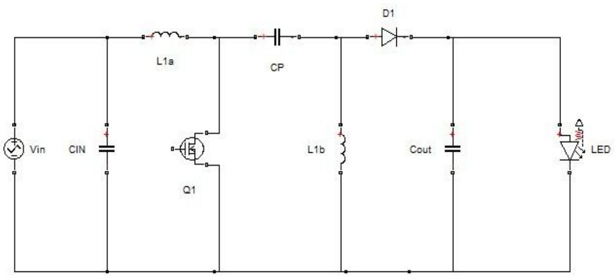

Fig7(a):Conventional SEPIC Converter

Modified SEPIC converter has known by its advantage for lower voltage stresses. Fig. 7(b) shows the proposed LED Lamp driver. Compared to the conventional SEPIC converter; the proposed Modified SEPIC converter differs in two ways. The capacitor C_P is a large bulk capacitor; a diode is placed in series with the inductor L_{1b}. The bulk capacitor serves to decouple the pulsating input power, and the diode insures that the inductor L_{1b} can be operated in discontinuous mode (DCM) without the capacitor C_P being charged to above the peak line voltage.

The inductor L_{1b} does not necessarily have to be operated in DCM but by insuring that no current can flow in the off' direction of D_2, the voltage V_{Cp} can arbitrarily be controlled by the ratio of L_{1a} to L_{1b}, as long as the sum of the output voltage and V_{Cp} is higher than the line peak voltage.

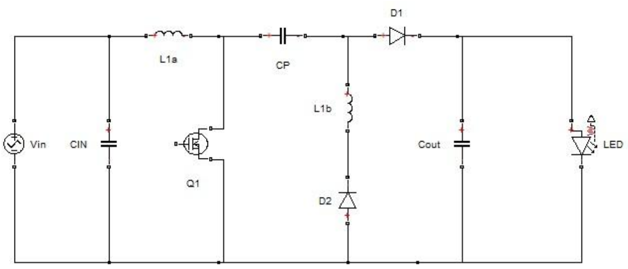

Fig7(b): Modified SEPIC Converter

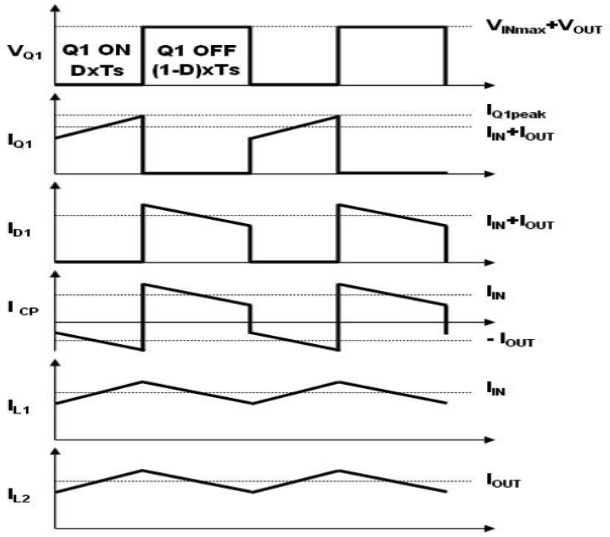

Fig 7(c):SEPIC Component current during CCM

VIII. PRINCIPAL OF OPERATION AND ANALYSIS

Figure7(a) shows a simple circuit diagram of a Modified SEPIC converter, consisting of an input capacitor C_{IN}; an output capacitor C_{OUT}; coupled inductors L_{1a} and L_{1b}; an AC coupling capacitor C_P; a power FET Q_1 and a diode D_1. Capacitor C_P is charged to the input voltage V_{IN}. Knowing this, we can easily determine the voltages as shown in Fig7(c). When Q_1 is off, the voltage across L_{1b} must be V_{OUT}. Since C_{IN} is charged to V_{IN}, the voltage across Q_1 when Q_1 is off is V_{IN} + V_{OUT}, so the voltage across L_{1a} is V_{OUT}. When Q_1 is on, capacitor C_P, charged to V_{IN}, is connected in parallel with L_{1b}, so the voltage across L_{1b} is $-V_{IN}$. The currents flowing through various circuit components are shown in Fig7(c)

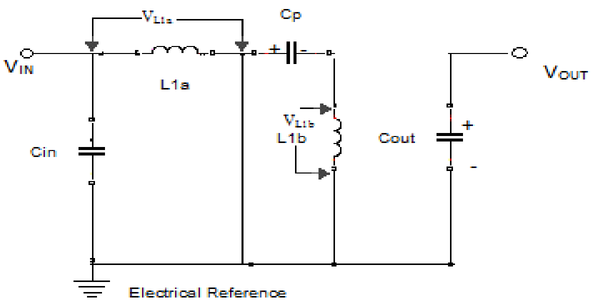

Fig 8(a): CCM during when Q_1 is on

When Q_1 is on, energy is being stored in L_{1a} from the input and in L_{1b} from C_P. When Q_1 turns off, L_{1a} current continues to flow through C_P and D_1, and into C_{OUT} and the load. Both C_{OUT} and C_P get recharged so that they can provide the load current and charge L_{1b}, respectively, when Q_1 turns back on.

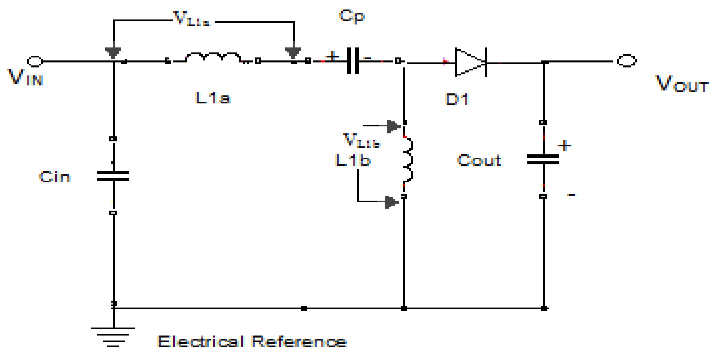

Fig 8(b) :CCM during when Q_1 is off.

IX. DESIGN OF PASSIVE COMPONENTS

A. Specification o f System

Input Voltage V_g = 140 V
Output Voltage V_o = 120 V
Switching Frequency f_s = 75 kHz
Switching Period T_s = 13.3 μ sec
Maximum Inductor Current = 1.5 A

B. Design of Input Inductor (L1)

From system specifications and circuit parameters inductance value is calculated using the following equation.

$$L_1 = \frac{Vg \times D}{\Delta Ir1 \times fs}$$

The inductance value was found as 160 μH.

C. Design of Output Inductor (L2)

For this inductor peak to peak ripple current is fixed to 5% of inductor current.

$$L_1 = \frac{Vo \times D'}{\Delta Ir2 \times fs}$$

Following same steps for this inductor as that of above inductor and using the above equation yields value of this inductance as 80 μH.

D. Design of Capacitor, C1

This capacitor is designed by fixing the voltage ripple to 10%.Value of capacitance can be calculated as follows,

$$C_1 = \frac{I2 \times D'}{\Delta Vr1 \times fs}$$

Capacitance value was found to be 180 μF.

E. Design of Output Capacitor, C2

Output capacitor is designed to filter out the ripple in load current. capacitance can be calculated as follows

$$C_2 = \frac{I2 \times D}{\Delta Vr2 \times fs}$$

Peak to peak ripple was fixed to 6% and substituting all other values as per system specifications capacitance value was found to be 82 µF.

X. CONTROLLER DESIGN CURRENT PROGRAMMED MODE CONTROL

Analog Current programmed mode control involves controlling of converter output voltage either by controlling peak or valley current of switch or inductor. It is called peak current mode control when maximum current of switch or inductor is compared with reference.

Output voltage of converter is continuously compared with reference voltage. Error obtained after comparison is fed to the controller, which generates a current reference i_{ref} .Whenever the switch is turned on inductor current starts increasing. This inductor current is continuously compared with reference generated by the controller. Switch is turned off for later part of switching interval when inductor current exceeds the reference. During turn off inductor current starts decreasing. Inductor current starts increasing when switch is turned on in next switching interval.

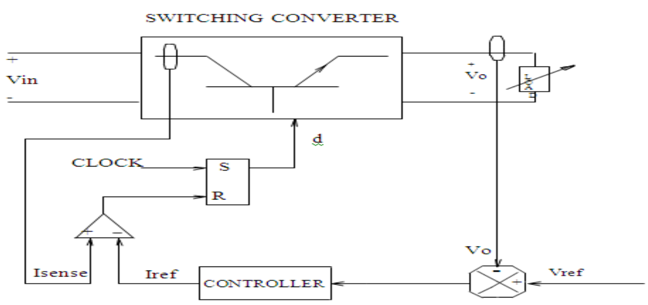

Fig 9: Schematic diagram of converter incorporating current mode control.

XI. DESIGN OF CONTROLLER:

As input voltage of the converter varies but we have to keep the output voltage at a constant value. So an appropriate controller is required to do this job. This controller will generate current reference for inner predictive loop; with the help of this current reference duty cycle for next switching cycle will be generated. Block diagram of this whole scheme is shown in Fig12.

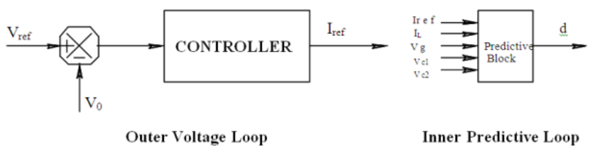

Figure 12 : Control structure

The transfer function of the system is:

$$G_{i(S)} = \frac{-3.526s^3+3.385e005s^2-6.769e009s+6.499e014}{S^3+6.316e004s^2+2.597e009s+9.419e013} \quad (a)$$

Now Eq(a) represents the required plant transfer function. Bode plot and root locus plot for the above plant are as shown in Fig11(a) and Fig11(b) respectively.

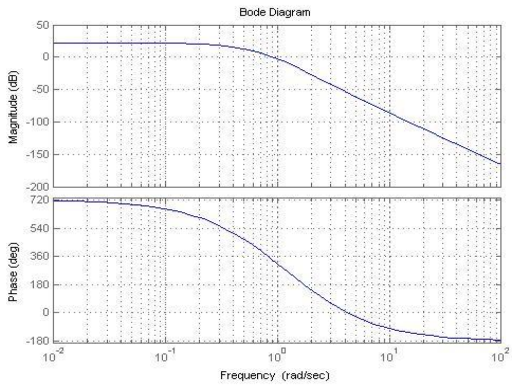

Fig 11(a) : Bode plot of uncompensated system

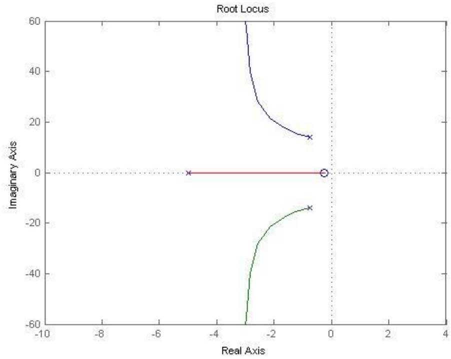

Fig11(b): Root locus plot of uncompensated system

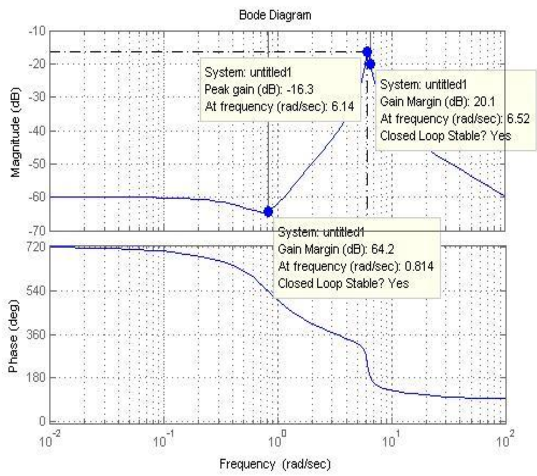

Fig11(c):Bode plot of compensated system

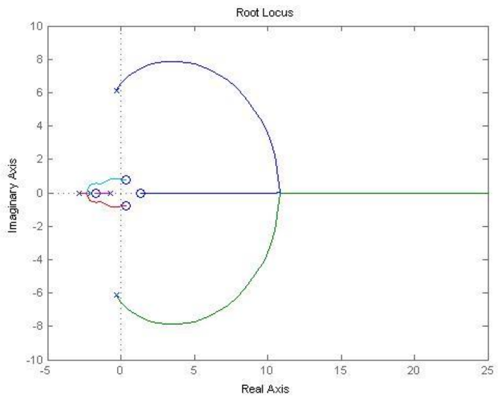

Fig11(d): Root locus plot of compensated system

XII. SIMULATION RESULTS

The performance of designed controller was put to test by simulating converter under different operating conditions and the results are obtained. Load is a resistive load and full load of the system is R=240 ohm. In each case controller performance can be observed.

(A) Open Loop SEPIC System.

For the open loop system we check the output at light load and full load and get the result of voltage and current of different component. In the case of open loop system the output is distorted so the system is unstable. There is no feedback across the output.

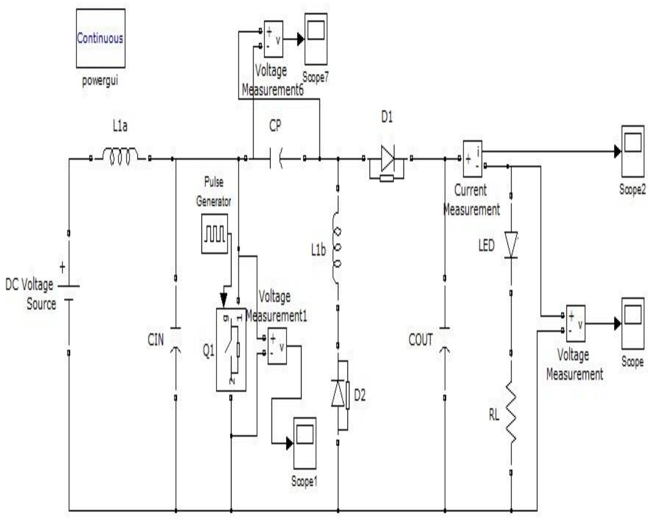

Fig12(a): Open loop SEPIC System

1. Open loop SEPIC System operating at light load

While simulating this load on the system was R= 20 ohm and input voltage was 140V. Output voltage and output current by the controller can be observed in fig12(b) and 12(c) respectively.

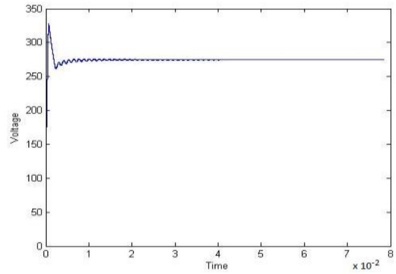

Fig12(b) : Output voltage at light load

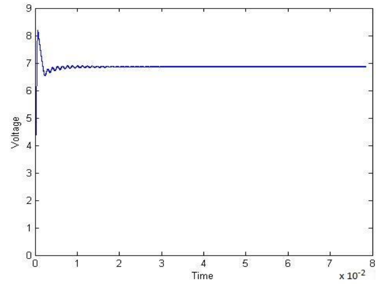

Fig12(c) : Output current at light load

2. Open Loop SEPIC System operating at Full Load.

Here controller was tested with full load R=240 ohm on the system. Here also we can observe current and voltage tracking the reference.

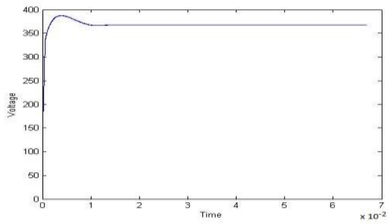

Fig12(e) : Output voltage at full load

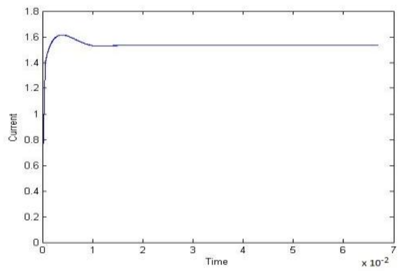

Fig12(f) :Output voltage across load at full load

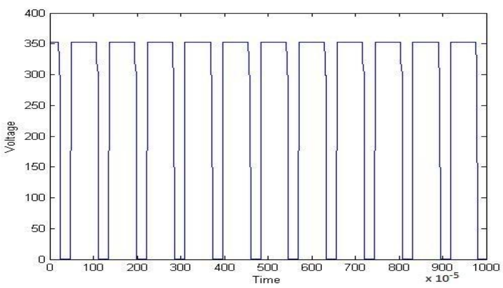

Fig12(g) : Voltage across switch at full load

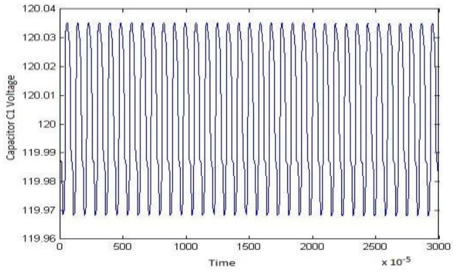

Fig12(h): Capacitor voltage across C_{out} at full load

*(A) Closed Loop SEPIC System***.**

For the closed loop system we check the output at light load and full load and get the result of voltage and current of different component. In the case of closed loop system the output is controllable so the system is stable. There is feedback across the output. Closed loop SEPIC system shown in Fig12(j).

1. *Closed loop SEPIC system at light load*

Closed loop results of SEPIC converter at light load circuit were presented here. While taking these readings input voltage was kept at 140V and period of switching was 13.3µ sec. Light load R=20 ohm.

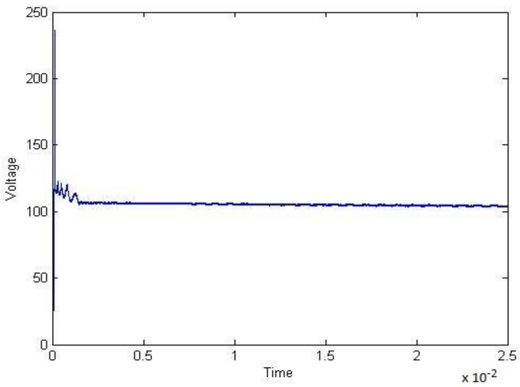

Fig12(i): Output voltage across load at light load.

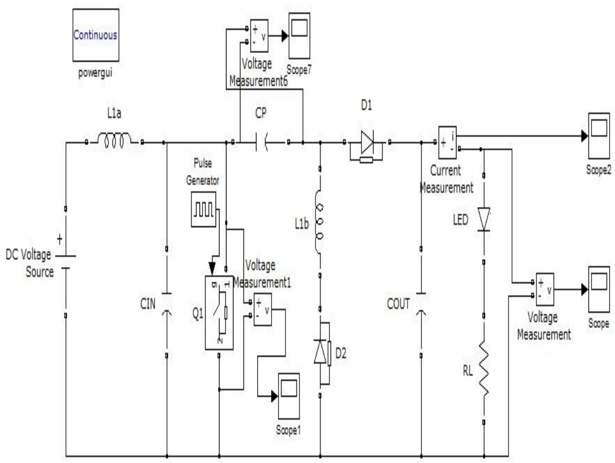

Fig12(j):Closed loop SEPIC system

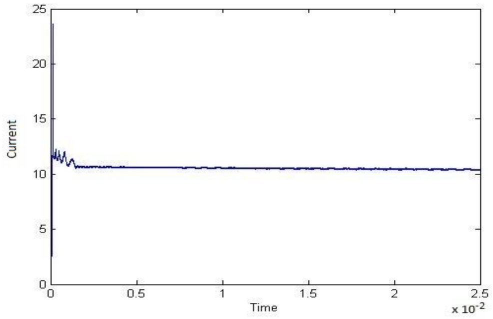

Fig12(k) : Output current across the load at light load

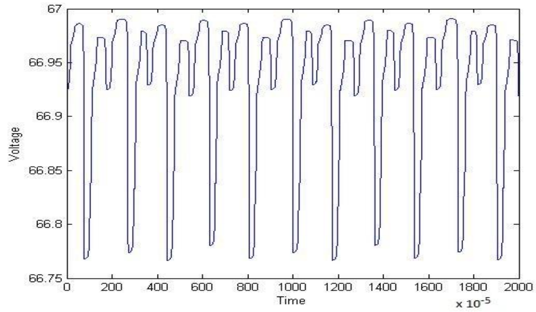

Fig12(l): Voltage across C_p at light load

2 .*Closed loop SEPIC system at full load.*

Closed loop system of SEPIC system shown in Fig 4.11. Result of voltage and current of different component at full load R=240 ohm shown below.

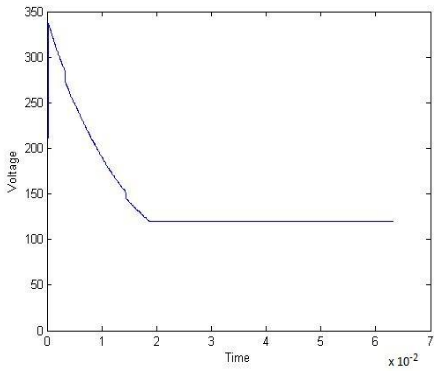

Fig12(m) : Output voltage across load at full load

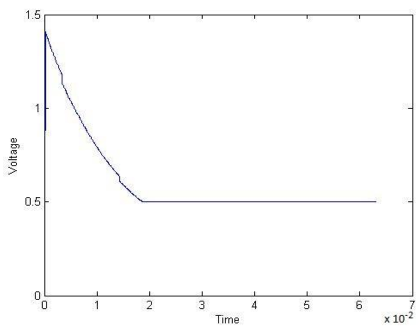

Fig12(n):Output current across load at full load

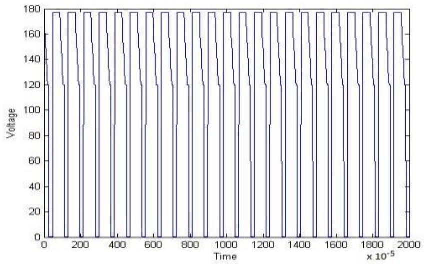

Fig12(o) : voltage across switch at full load

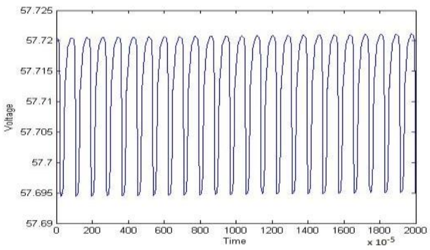

Fig12(p):Voltage across C_p at full load

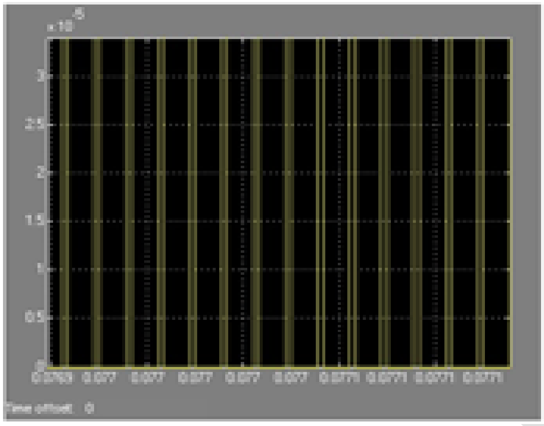

Fig12(q) : MOSFET gate signal

CONCLUSIONS

This paper addresses design and implementation of peak current mode controlled SEPIC converter that can be used in low power applications.

General structure of LED lamp driver system was explained and a suitable power supply structure was proposed for lighting applications. SEPIC converter was chosen to generate a fixed DC voltage from variable DC available at supply.

Modelling of SEPIC converter under perturbed conditions was done using state space averaging approach. Passive components required for SEPIC converter are designed. SEPIC converter is a 4th order system so predictive peak current mode control was chosen because it offers simple dynamics and inherent peak current protection. Developed mathematical along with designed controller is simulated using MATLAB/Simulink.Controller performance was checked for different operating conditions. In each case it was observed that both output voltage and inductor current are tracking their references.

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