An Improved Modified Sepic Converter for High-Luminance Lighting LED Lamps

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Abstract—The efficiency and lifetime of light-emitting-diode (LED) lamps are approaching and exceeding that of fluorescent lamps. LED light sources are finding more applications than conventional light bulbs due to their compactness, lower heat dissipation, real-time color changing capability and most importantly, long life which is much longer life than that of conventional offline power converters. In these offline applications, high power factor, and low harmonics are of primary importance.

The modified SEPIC-type PFC not only can achieve unity power factor but reduce de-link voltage to release component stresses. Therefore, it is suitable for high line-voltage applications. It is also important to step up/down voltage with simple single-stage conversion for low cost and high efficiency. A SEPIC converter is particularly suitable for non-isolated application since it is single stage, and can step up/down, and of high power factor as it is run in discontinue conduction mode. The harmonics of the input line current is reduced and power factor is high because the input inductor current follows the input voltage. 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, voltage step-up and down, high power factor and dimmable LED current.

Keywords—SEPIC Converter, LED, MATLAB, Constant Current Control, Stability

I. INTRODUCTION

About 19% of the electric power in the United States is for residential, commercial or industrial lighting. The commonly used lighting technologies include incandescent and halogen bulbs, fluorescent and compact fluorescent lamps (CFL), and high intensity discharge (HID) lamps. Generally, the efficiency of the lighting sources is indexed by efficacy, or lumen per watt. The efficacy of typical energy saving CFL lamps is around 7~8%, compared with 2% for the conventional the incandescent bulbs. Obviously, the savings of energy by replacing the incandescent bulbs with CFL is huge owing to the higher efficacy. With the advancement of new materials and manufacture process, a new lighting source, that is, high brightness LED are now attracting more and more attention from both academy and industry. In fact, LED has been used for decades for low brightness applications in display, signal and signs, such as LCD backlighting, automotive braking lighting, traffic lighting, etc. It is also used as lighting sources for some special cases, such as automotive indoor lighting, photographic flash, emergency lighting, etc. However, it is only recently as the introduction of high brightness white LED, that wide application in lighting becomes possible. For instance, in 2006, Cree Inc. demonstrated a prototype with a record white LED luminous efficacy of 131 LM/W.

LED is not sensitive to shock, vibration or quick environment change. It has very long lifespan (100,000 hours which is more than 10 times of CFL), and high turn on/off times. This means a great reduction of the cost, time, and effort for the replacement of the lightings.

LED is compact and can be installed on Printed Circuit Board (PCB). In addition, it is easy to drive compared with the traditional sources. Therefore, practical application of LED lighting in industry, commercial and residential is of great interest to both academy and industry.

Currently, fluorescent lamps are the most popular lighting solution due to their high luminous efficacy and low running cost. Much research has been directed toward improving fluorescent lighting systems. However, because of their limited programmability, fluorescent lamps cannot meet the requirements of many modern applications. Unlike fluorescent lamps, red-green-blue (RGB) light-emitting-diodes (LEDs) having capability of generating instantly different light colors and intensities are expected to find many applications in such areas as biomedical apparatus [1], detector system [2], liquid crystal display (LCD) back lighting [3], general decorative illuminations, etc. Thus, LEDs are expected to become a major kind of light sources in the coming decades [4].

II. STRUCTURE OF LED LAMP

The design of LED lamp driver using SEPIC converter shown in Fig.1 and having the following sections:-

- Energy Source
- Fixed DC conversion
- Controller
- Power distribution

In this dissertation DC supply has been used in the circuit for the converter. If the supply is AC then this supply is fed to the Bridge rectifier then a variable DC is achieved. For the ideal condition a DC supply has been used in the circuit and the 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 down or step up using converter to supply different loads.

![Fig.1 Structure of LED Lamp Driver Using SEPIC Converter](image)

The variations are overcome in the output of the load. Controller is used for removing this variation from the output and a constant current across the load is achieved. Power distribution section convert DC bus voltage into different voltage levels as per the need of other subsystem of any device.

III. CURRENT MODE CONTROL

The circuit diagram of Current mode controlled shown in Fig.2, and this figure involves controlling of converter output voltage either by controlling peak or valley current of LEDs. It is called peak current mode control when maximum current of LEDs is compared with reference current.

![Fig.2 current mode control](image)

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 then the LEDs current starts increasing this inductor current is continuously compared with reference generated by the controller. Switch is turned off or later part of switching interval when LEDs current exceeds the reference. During turn off LEDs current remains constant. Inductor current starts increasing when switch is turned on in next switching interval.

The peak of LEDs current is controlled in every switching interval in the current control mode.

IV. PRINCIPLE OF OPERATION

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.5 relies on using the conventional SEPIC PFC converter shown in Fig.3 operating 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 \((V_{in} + V_{out})[5]\).

![Fig.3 Conventional SEPIC Converter](image)

Fig.4 shows the different current and voltage waveform during when the switch is ON and OFF. In this time the current flowing in the inductor \( L_1 \) and \( L_2 \) is continuous in nature. When switch is ON then the current is continuously.

Modified SEPIC converter has known by its advantage for lower voltage stresses. Fig.3 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 \( L_1 \). The bulk capacitor serves to decouple the pulsating input power, and the diode insures that the inductor \( L_1 \) can be operated in discontinuous mode (DCM) without the capacitor \( C_1 \) being charged to above the peak line voltage [3]. The inductor \( L_1 \) 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 \( V_{C1} \) can arbitrarily be controlled by the ratio of \( L_1 \) to \( L_2 \), as long as the sum of the output voltage and \( V_{C1} \) is higher than the line peak voltage.

![Fig.4 SEPIC Component current during CCM](image)
Fig. 5 shows a simple circuit diagram of a Modified SEPIC converter, consisting of an input capacitor $C_{\text{in}}$, an output capacitor $C_2$, coupled inductors $L_1$ and $L_2$, an AC coupling capacitor $C_1$, a power FET $Q_1$, and a diode $D_1$. Capacitor $C_2$ is charged to the input voltage $V_{\text{in}}$.

\begin{align}
L_1 \frac{di_1}{dt} &= v_s \\
L_2 \frac{di_2}{dt} &= v_{c1} \\
C_1 \frac{dv_{c1}}{dt} &= -i_2 \\
C_2 \frac{dv_{c2}}{dt} &= -\frac{v_{c2}}{R} \\
\end{align}

(1)

Off State Equation,

\begin{align}
L_1 \frac{di_1}{dt} &= v_8 - v_{c1} - v_{c2} \\
L_2 \frac{di_2}{dt} &= -v_{c2} \\
C_1 \frac{dv_{c1}}{dt} &= -i_1 \\
C_2 \frac{dv_{c2}}{dt} &= -\frac{v_{c2}}{R} + i_1 + i_2 \\
\end{align}

(2)

\[ G_{\text{in}}(s) = \frac{3.526s^3 + 3.385e005s^2 - 6.769e009s + 6.499e014}{s^3 + 6.316e004s^2 + 2.597e009s + 9.419e013} \]

(3)

Now Eq 3 represents the required plant transfer function.

For the Fig.7, When $Q_1$ is off; the voltage across $L_1$ must be $V_{\text{out}}$. Since $C_{\text{in}}$ is charged to $V_{\text{in}}$, the voltage across $Q_1$ when $Q_1$ is off is $V_{\text{in}} + V_{\text{out}}$, so the voltage across $L_1$ is $V_{\text{out}}$. For the Fig.6, When $Q_1$ is on; capacitor $C_1$, charged to $V_{\text{in}}$, is connected in parallel with $L_1$, so the voltage across $L_2$ is $-V_{\text{in}}$. The currents flowing through various circuit components are shown in Fig.4.

V. SIMULATION RESULT

The simulink model of the closed loop SEPIC converter shown if Fig.8. For the closed loop system 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 controller has been used for controlling the output.

During the simulation time the input voltage is 140V and switching frequency is 75kHz. The PI Controller is used in the feedback loop and the $K_p = 0.045$ and $K_i = 0.91$. 

On State Equations,
Closed loop system of SEPIC system shown in Fig.8. Result of voltage and current of different component at full load R=240 ohm and R= 20 ohm shown below. The value of $K_p=0.045$ and $K_i=0.91$. Reference voltage is fixing at 120 V.

Fig.(9) shows output voltage and current for LEDs at light load. In this time the rise time is 0.0014 sec and settling time is 0.0041 sec.

Fig.(10) shows output voltage and current for LEDs at full load. In this time the rise time is 0.00021 sec and settling time is 0.018 sec.

Fig.(12-13) shows output voltage across switch is 178V and Capacitor voltage across C2 is 120V.
The transfer function has been calculated and Bode plot and Root locus plot for compensated and uncompensated system has been described for stability purpose.

VI. CONCLUSION

General structure of LED lamp driver system has been explained for lighting applications. SEPIC converter has been selected to generate a step up or step down DC voltage.

Modelling of SEPIC converter under perturbed conditions has been done using state space averaging approach. A current feedback loop is proposed to control the LED brightness. The gate drive signal of the switch is generated by comparing the saw-tooth carrier signal with the current feedback signal. This circuit has the advantages of non inverted output, simple feedback control, and voltage step-up and down, high power factor and dimmable LED current.

The transfer function of the system is obtained and the stability is checked by the Bode plot and Root locus plot. It is observed that the stability response of the system is used perfectly stable. The simulation results of the SEPIC converter obtained for the open loop and closed loop system at light and full load condition has been analysed. It is observed that the output response of the closed loop system gives more correct result as compare to open loop system. It is analyzed from the closed loop system response that the settling time is less as compared to open loop system.

REFERENCES


