

A Highly Efficient SEPIC-Flyback Integrated Converter as an LED Driver

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ABSTRACT: Light-emitting diodes (LEDs) have been widely used for various lighting applications. A high power factor single-stage single-switch driver can be used to supply LEDs without using an electrolytic capacitor. By integrating the single-ended primary inductor converter (SEPIC) and flyback converter, LED driver could achieve nearly a unity power factor and low total harmonic distortion (THD). Since leakage energy is absorbed, there are no voltage spikes across the switch when it turns off. The SEPIC circuit is operated at discontinuous conduction mode (DCM) and there is only one active power switch which turns on under zero current switching (ZCS). Operating principles of the driver is discussed in detail. Simulation is done and results are presented to verify the theoretical analysis.

KEYWORDS: Single Ended Primary Inductance Converter (SEPIC), Flyback converter, Single-stage single-switch, Discontinuous conduction mode (DCM), Power Factor Correction, Light-emitting diode (LED) Driver.

I. INTRODUCTION

LEDs have become increasingly common in our daily lives. With the advantages of superior longevity, fast response, small size and colour rendering, they are well suited to indoor and outdoor energy saving lighting applications, such as traffic lighting, displays, street lighting, decorative lighting and so on[1]. Since the package and costing technology are getting improved, the cost of LEDs decrease greatly, with a great potential to replace existing lighting sources such as fluorescent lamps. Being mercury free, it is less harmful for our environment.

To meet the power factor (PF) requirements, designers have to use power factor correction (PFC) techniques that improve the low frequency harmonic contents of power systems. Earlier methods for power factor correction (PFC), suggested a basic dc-dc converter [2]. But voltage ripple across the output capacitor is a major drawback in this method. To overcome this a second stage is required. A two stage LED driver is constructed by a dc-dc converter with a power factor correction (PFC) stage. The PFC stage achieves nearly a unity power factor and a low harmonic distortion, while the dc-dc converter provides a well regulated output.

Though it is easy to design, the two stage LED driver is having high cost, since it needs more than one independently control circuits and power switches. This topology results in lower efficiency because of processing the power twice. A single stage LED driver is introduced, which consists of a PFC stage and a dc-dc converter by sharing active power switches and control circuits. This structure which has less components and lower complexity is suitable for low power applications. Compared to the traditional two stage converters, this single stage solution saves one power switch and control circuit. But still driver circuit for two switches needs to design, which would increase the cost and reduce the reliability of the system.

To overcome this problem, it is necessary to reduce number of switches in the LED driver circuit. Therefore single-stage single-switch LED drivers were introduced [3]. Flyback is a widely used single-switch topology due to its minimal component account and low cost. A SEPIC circuit is chosen and designed to operate in DCM for PFC stage

and it can achieve a unity power factor. SEPIC provides an inherent input current filtering, so that an LC filter can be saved. An isolated single-stage single-switch PFC converter for LED driver is introduced which is composed of a single ended primary inductor converter (SEPIC) integrated with a flyback converter and no electrolytic capacitors are used.

Paper is organized as follows. Section II describes the operating principles and modes of operation of converter. The voltage and current across different components are presented. Section III presents simulation results showing the power factor corrected output of the converter. Finally, Section IV presents conclusion.

II. BASIC OPERATING PRINCIPLES

Fig. 1 shows the LED driver based on integrated SEPIC and flyback converter. There are six operating modes during one switching cycle in steady state condition. To simplify the circuit analysis, some assumptions are made:

1. All the components are ideal.
2. The capacitors C , C_B and C_o is large enough that their voltages are constant.
3. The switching frequency is much larger than line frequency
4. The transformer turns ratio is defined as $n = N_p/N_s$

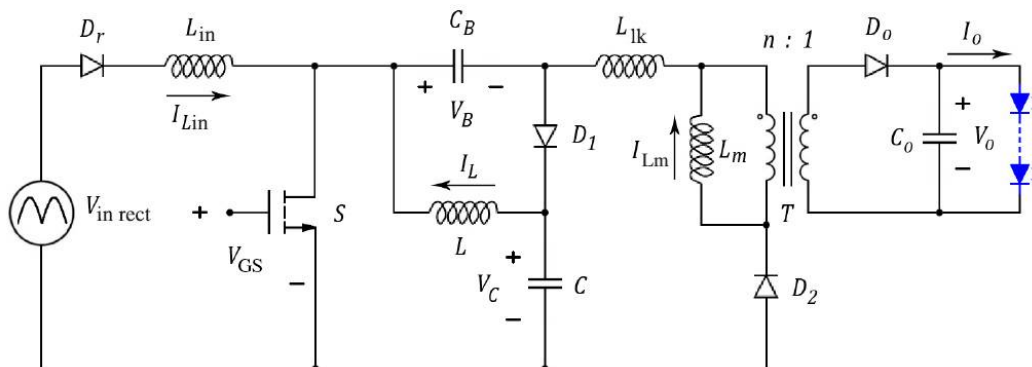


Fig. 1 Equivalent circuit diagram of the LED Driver

1. **MODE 1 ($t_0 - t_1$)**
When switch S turns ON, voltages $V_{in\ rect}$, V_C , and V_B are applied to the inductors L_{in} , L and $L_m + L_{lk}$ respectively. The inductor current increases linearly from zero. The diodes D_1 and D_0 are reverse biased. T_s is the time period and D is the duty cycle. When switch S turns OFF, mode 1 ends.
2. **MODE 2 ($t_1 - t_2$)**
When switch S turns OFF, diodes D_1 and D_0 start conducting. Since D_1 is conducting, Voltage across switch will get clamped. The voltage $V_C - nV_0$ is applied to the inductor L_{lk} inversely and its current decrease linearly to zero and hence leakage energy is absorbed. Diode D_2 turns off at ZCS condition and mode 2 ends.
3. **MODE 3 ($t_2 - t_3$)**
During this mode, the voltages $-(V_B + V_C + V_{in\ rect})$, $-V_B$ and $-nV_0$ are inversely applied across L_{in} , L and L_m respectively. Therefore current through the inductors decrease linearly and comes to zero. $I_{L\ in}$ reduces to zero first and mode ends.
4. **MODE 4 ($t_3 - t_4$)**
In this mode diodes D_1 and D_0 are still conducting and when I_L becomes zero, diode D_1 turns off under zero current switching condition.
5. **MODE 5 ($t_4 - t_5$)**
In this mode, current $I_{L\ m}$ is decreasing and no other inductor current is present. When $I_{L\ m}$ becomes zero, diode D_0 turns OFF under ZCS condition.
6. **MODE 6 ($t_5 - t_6$)**
During this mode, the output capacitor C_o provides the load current. This mode continues until the switch turns ON again.

The main waveforms of the LED driver is presented in Fig 2.

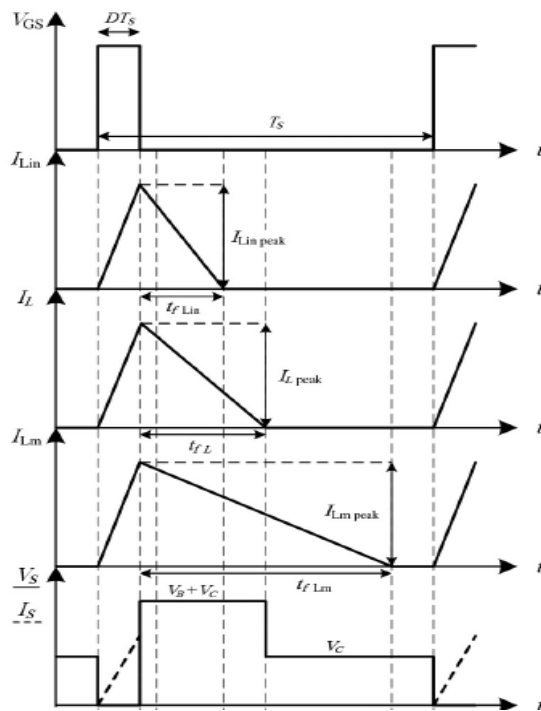


Fig. 2 Main waveforms of the LED Driver

III. EXPERIMENTAL RESULTS

In order to verify the theoretical analysis, a Simulink model to supply a 21W/30 V LED module is implemented and required waveforms are obtained. Parameters of the model are shown in Table 1.

Table1. Parameters for the Simulink model

PARAMETERS	VALUE
Output power	21W
Output voltage	30V
Input voltage	220Vrms
Switching frequency	50KHz
Duty cycle	0.1
Inductor L_{in}	430 μ H
Inductor L	870 μ H
Inductor L_m	300 μ H
Turns ratio, $n = N_p/N_s$	1.2
Capacitor C_B	2.2 μ F
Capacitor C_0	7mF

Simulink model for LED driver is shown in Fig.3 and the waveforms associated with it is presented in Fig.4

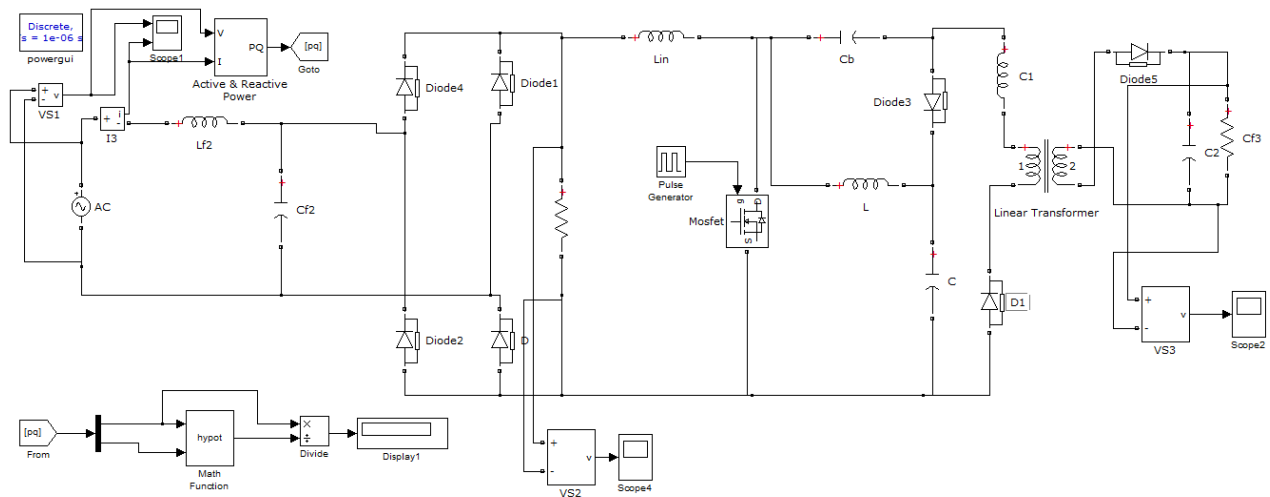


Fig. 3 Simulink Model

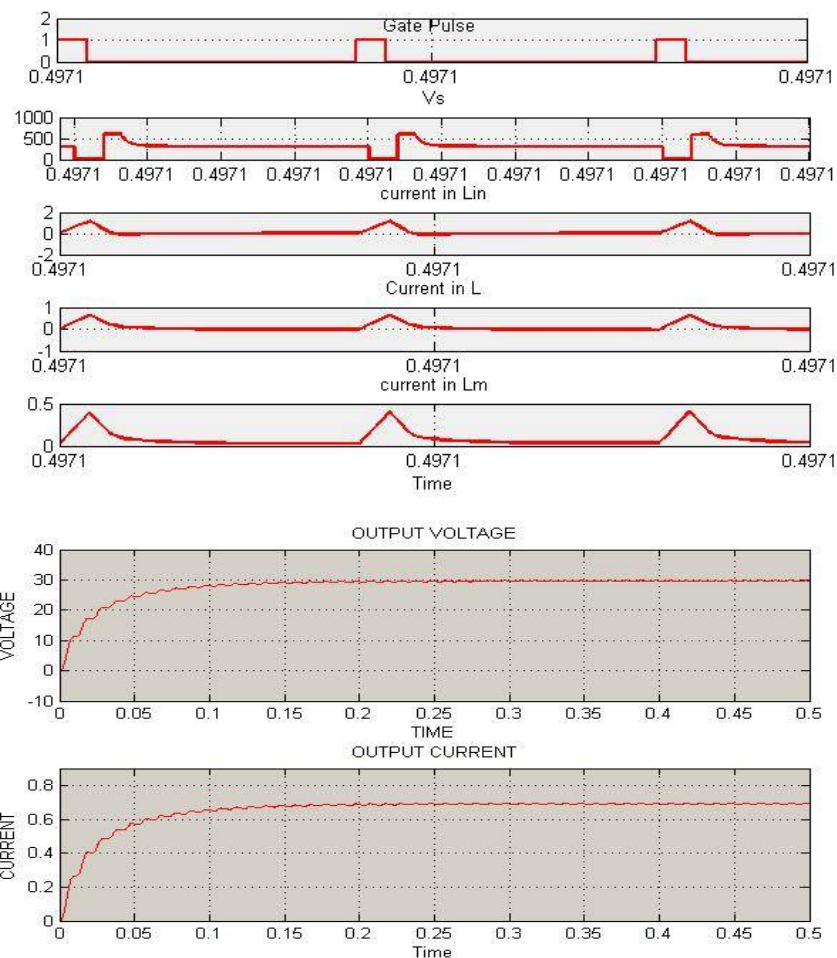


Fig. 4 Waveforms of voltage and current through circuit components.

IV. CONCLUSION

A single stage single switch LED driver is introduced. The SEPIC converter provides power factor correction and a well regulated output is given by flyback converter. As there is only one active switch in power circuit, design complexity is reduced and reliability of the system could be improved. A nearly unity power factor in full load condition can be achieved.

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