



RESEARCH ARTICLE

A PEAK CURRENT MODE CONTROLLED SEPIC LED DRIVER DESIGN CONSIDERING  
POWER FACTOR AND FLICKER

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ABSTRACT

In this paper, a peak current mode controlled single ended primary inductor converter (SEPIC) LED driver is proposed to control the brightness of the LED. One string of 37 series connected LEDs is adopted as output of the circuit. The proposed control strategy is based on measuring MOSFET peak current value using a shunt resistor. When this voltage reaches peak threshold value, controller turns off MOSFET. The output current is adjusted to desired levels by changing this peak threshold value. The power factor in the AC power supply side is low because of the full wave bridge rectifier with capacitor filter at the input of the converter. The proposed control strategy is applied with power factor correction (PFC) circuit where input voltage is multiplied by control voltage to achieve high power factor. In PFC circuit, although the line current waveform is slightly distorted due to voltage limitations in integrated circuit (IC) chip used for the proposed control strategy, power factor is kept above 0.9 for operation region between 100mA-300mA. In addition, flicker on LED string is measured for operating current region and flicker limits are revealed. Adjustable output current levels, low flicker on LED string, MOSFET peak current control at each cycle, fast output dynamics, and high power factor are acquired by the proposed control strategy.

**Keywords:** Light emitting diode, Peak current mode control, Flicker, Power factor correction circuit, Single ended primary inductor converter

1. INTRODUCTION

Nowadays, light emitting diodes (LEDs) are preferred in general lighting applications due to their high luminous efficacy, long lifetime, robustness, and small size [1, 2]. Halogen bulbs, fluorescent and compact fluorescent lamps (CFL) and high intensity discharge (HID) lamps are some of the other lighting technologies used in the industrial, commercial and residential lighting [3]. Lighting applications forms a large part of electricity consumption in the world. Hence, the most important subject when designing a lighting system is to reduce energy consumption and increase efficiency like in any other electrical system/application. Therefore, classical bulbs have been replaced with LEDs in recent years since they use less electricity and generates less thermal dissipation. Moreover, LEDs are environment friendly because they do not contain any mercury like the fluorescent lamps [3, 4].

However, the driver circuit plays remarkable role in dominating the energy efficiency. The overall system efficiency can be increased with an appropriate driver circuit [4]. Classical LED drivers can be subdivided into single-stage and two-stage LED drivers [4,5]. Single stage driver is a dc/dc converter with constant output current which can accomplished by power factor correction. Two stage driver has PFC circuit that is responsible for high power factor and dc/dc converter, separately. With the advancing technologies, integrated-stage topologies which can merge PFC stage and dc/dc stage into one stage by sharing active power switches and control circuits are designed to overcome the large size and high cost

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of the two stage converters [4]. High efficiency, high reliability, and fast output dynamics can be acquired by integrated stage converters. A current loop is mostly included to control stage of dc/dc converter to obtain constant current control, since the LED luminosity depends on the current flowing through LED lamp. Furthermore, a current balance stage will be needed when multiple arrays of LEDs are adopted [4,6].

Many circuit topologies and control algorithms have been developed to improve system power factor for LED drivers. Passive power factor correction and active power factor correction circuit topologies are well explained in [7] for researchers interested in PFC circuits. Among them, well known active power factor correction switch mode power supplies such as buck, boost, buck-boost, Flyback and fourth-order CUK, SEPIC and Zeta converters etc. can be used as LED drivers while keeping the PF close to unity. These converters can operate in continuous conduction mode (CCM), discontinuous conduction mode (DCM), and boundary conduction mode (BCM). In addition, SMPS used for LED drivers can be classified according to the converter whether it is isolated/non-isolated or step-up/step-down.

Furthermore, PFC LED drivers can be categorized according to control techniques such as current mode control and voltage mode control. Several known methods related with current mode control are average current control, peak current control, and  $I^2$  average current control. In addition, there are digital PFC control techniques that are expected to replace the analog PFC control techniques due to development in digital circuits [7].

Another key point is light modulation which is also called as flicker, flutter, and shimmer. Flicker is defined as “variations of luminance in time” [8]. Percent flicker (Modulation%) and flicker index are the most commonly used metrics to quantify this variation [8,9]. All light sources may flicker with various levels. However, the flicker exists in LED lighting when AC to DC conversion is present. In that case, LED lamps will have a peak-to-peak current ripple at twice the line frequency (100 Hz to 120 Hz). Hence, the flicker is mainly dependent on the driver circuit for LED sources. Visible (3 Hz to 70 Hz) and invisible flicker can have potential risks on human health. Health risk and biological effects of flicker cannot be ignored where headache, eyestrain, and seizures are some of them [8].

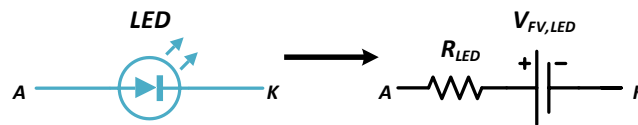
In literature, an average current controlled SEPIC LED driver is proposed in [2,10]. High power factor and low THD are obtained. A peak current mode controlled PFC LED driver is proposed in [11]. With a special selection of the compensation slope, minimum THD levels are obtained. This control strategy allows cycle-by-cycle control. A voltage controlled dc-dc SEPIC LED driver is proposed to be used in automotive and railway LED applications in [6]. Single stage high power factor SEPIC LED driver is proposed in [12] where SEPIC inductors are realized in the same core. The compatibility of input current harmonic spectrum to IEC 61000-3-2 standard is examined. A single stage single switch LED driver based on the integrated SEPIC circuit and Class-E resonant converter is proposed to be used for street lighting system in [13]. High power factor is obtained by operating the SEPIC converter in discontinuous conduction mode. Soft switching is achieved by resonant converter, so that switching losses are reduced and system efficiency is improved. A PWM dimmable digital LED driver is proposed to control the brightness of LED in [14]. PIC16F877A microcontroller generates 1.95 kHz PWM signal to dim the LED. Various duty cycles of PWM results in different LED current and luminous flux without flickering. A dc-dc boost converter with PWM dimming control is presented to be used in automotive lighting applications in [15].

In this study, the single-ended primary inductor converter (SEPIC) that can be designed for a wide range of input and output ratios is chosen as adjustable current LED driver. SEPIC converter has the same polarity as the input. As for the control technique, peak current mode control is chosen to control LED brightness, where LED current is adjusted by a control voltage. Hence, the consumers can adjust LED brightness depending on their needs. Also, the high power factor is achieved by the proposed control strategy to increase energy efficiency. Flicker on LED string are also measured for different output current levels and tested whether it is harmful or not for human health.

This paper is organized as follows: In Section II, the electrical characteristics of LED string is given. Design considerations of SEPIC power stage and controller are explained in section III. Simulation results of complete LED driver including power and control circuits are discussed in Section IV and conclusion is provided in Section V.

## 2. ELECTRICAL CHARACTERISTICS OF LED

Electrical equivalent model of a single LED consists of an internal resistance  $R_{LED}$  and a forward biased voltage  $V_{FV,LED}$  as shown in Figure 1.



**Figure 1.** Equivalent circuit of a single LED.

The voltage-current characteristic of the LED is similar to diode. LED does not conduct until the applied voltage between anode and cathode node is equal to or greater than forward voltage of the LED. Forward voltage of the LEDs is differed by the color of LED. Typical drive voltage for High Brightness LEDs is about 2.5V to 4V. The operation current of the LED is usually about 50-300 mA and produced illumination is considerably weak by a single LED [16]. Therefore, in order to obtain the enough lighting levels, multiple LED chips are generally connected in series and/or parallel [1,17].

However, LEDs are required a proper driver circuit and direct current (DC) operation. In general, this DC voltage is rectified from an AC power supply by an uncontrolled full wave bridge rectifier. Then, a DC-DC converter regulates the output voltage/current depending on the power needs of the LED string. If multiple LED chips are connected in series, the output voltage of the DC-DC converter must supply at least total forward voltage of LED's, regardless from voltage variations in AC power supply [18]. Therefore, in switch mode drivers, a voltage feedback or/and current feedback which is mostly included into control stage provide a stable operation to LED string. Among the current mode control techniques, peak current mode control is a good choice by means of current regulation, together with over-voltage protection. In Figure 2, general current mode-controlled AC-DC LED driver is illustrated. There are other LED driver techniques such as resistive current limiting also called as linear LED driver, pulse width modulation dimming. The suitable driver circuit can be chosen for various application needs like automotive lighting, street lighting, household lighting, and commercial lighting and many others.

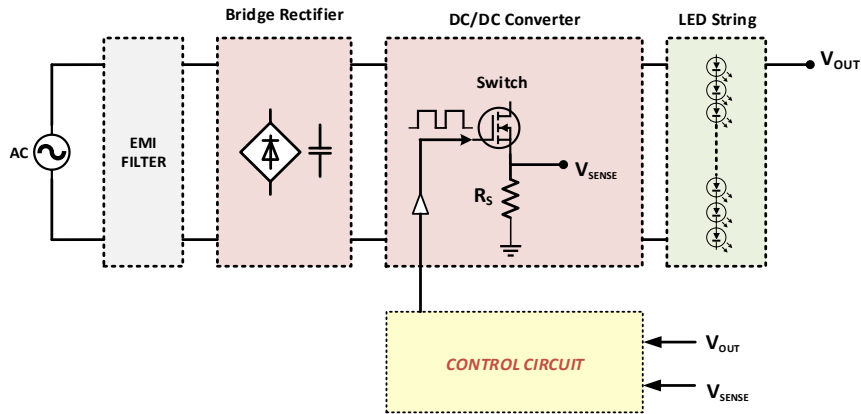


Figure 2. General current mode-controlled LED driver representation.

### 3. LED DRIVER DESIGN

Design criteria and goals of the system are given in Table 1. Output of the circuit consists of 37 series connected LED chips with adjustable current levels. SEPIC converter which is assumed to be working in continuous conduction mode is selected as LED driver. Selection of inductors and capacitors of the converter are provided in power stage, while proposed peak current mode control is explained in control stage.

Table 1. Design criteria for LED driver.

Parameters	Symbols	Values
Input Voltage	$V_{IN}$	180V~260V AC 250V~360V DC
Output Voltage	$V_{OUT}$	100V
Output Current	$I_{OUT}$	50mA~300mA
Line Frequency	$f_L$	50Hz
Switching Frequency	$f_s$	100kHz
Peak-to-Peak Current Ripple	$\Delta I_L$	40%
Peak-to-Peak Output Voltage Ripple	$\Delta V_{OUT}$	2%
Power Factor	PF	$\geq 0.9$

#### 3.1. Power Stage

The representation of AC-DC LED driver without the control stage is shown in Figure 3. Load is chosen as 30 Watt LED with 37 LED connected in series, while each LED having 2.7 V forward biased voltage and  $1\Omega$  internal resistance. Output voltage  $V_{OUT}$  is 100V, while output current  $I_{OUT}$  is 300 mA. SEPIC regulates the output voltage by switching the MOSFET on and off at constant frequency.

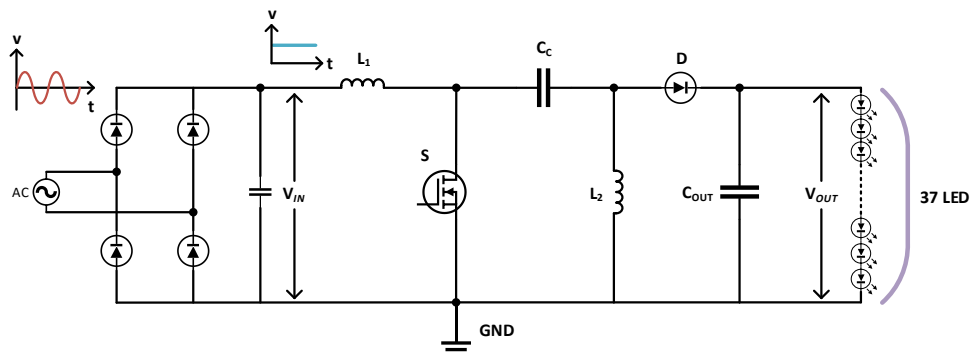


Figure 3. Representation of driver.

For a SEPIC converter operating in a continuous conduction mode (CCM), the duty cycle is given by following formula if the voltage drop of the diode  $V_D$  is assumed to be 0 V [19].

$$D = \frac{V_{OUT}}{V_{IN} + V_{OUT}} \quad (1)$$

Where, D is the switch duty cycle,  $V_{IN}$  is the input voltage of the SEPIC, and  $V_{OUT}$  is the output voltage. The output voltage can be lower, higher than, or equal to input voltage by adjusting the duty cycle.

The input voltage of the proposed SEPIC converter varies between 250 V and 360 V of DC voltage. While the minimum duty cycle occurs at maximum voltage, maximum duty cycle occurs at minimum voltage. Therefore, the minimum and maximum duty cycles are defined as:

$$D_{min} = 0.2174 \leq D \leq 0.2857 = D_{max} \quad (2)$$

The inductance value has been selected from peak-to-peak current ripple that is allowed to be 40% of the average value for the worst case of operation. Whilst the highest input current occurs at the lowest input voltage value, the change from peak-to-peak current can be defined as:

$$\Delta I_L = I_{in} \cdot 40\% = I_{out} \cdot \frac{V_{out}}{V_{in(min)}} \cdot 40\% = 0.048 \text{ A} \quad (3)$$

When the switching frequency is selected as 100 kHz, the values of the inductances  $L_1$  and  $L_2$  are determined as follows:

$$L_1 = L_2 = L = \frac{V_{in(min)}}{\Delta I_L \cdot f_{sw}} D_{max} = 14.88 \text{ mH} \quad (4)$$

Where,  $f_{sw}$  is the switching frequency.

Assuming that the voltage ripple on the coupling capacitor is 10% of the DC input voltage, the value of coupling capacitor is calculated by following formula:

$$C_C = \frac{I_{OUT} \cdot D_{max}}{\Delta V_{CC} \cdot f_{sw}} = 0.1 \mu\text{F} \quad (5)$$

In order to prevent the large output ripple when no bulk capacitor is used for PFC circuit, output capacitor is calculated as follows:

$$C_{OUT} = \frac{I_{OUT}}{\Delta V_{OUT} \cdot 2\pi f} = 477 \mu\text{F} \quad (6)$$

where  $\Delta V_{OUT}$  is assumed to be 2% of the output voltage which is 2V.

### 3.2. Control Stage

General peak current mode controlled SEPIC LED driver diagram is given in Figure 4. The system consists of a voltage feedback for outer loop and current feedback for inner loop. The MOSFET current is sensed by a resistor ( $R_{SENSE}$ ) in series to the MOSFET, and then compared with the current reference ( $I_{REF}$ ) by PWM comparator. By controlling the reference current, the output current can be adjusted. In this study, the switch peak current value is controlled. The switch current will be equal to sum of the two inductors' current, when the switch is closed in SEPIC converter. Therefore, controlling the switch peak current value provides the control of the output current as well. Mathematically, the output current can be written as a function of switch current as in equation (10). Firstly, the switch peak current is given in equation (7), when the switch is closed.

$$I_{switch(peak)} = I_{L1} + \frac{\Delta i_{L1}}{2} + I_{L2} + \frac{\Delta i_{L2}}{2} \quad (7)$$

In steady-state, it is known that the average current of inductor  $L_1$  is also the input current of the SEPIC converter and the average current of inductor  $L_2$  is the output current. The unique power equation below can help to define input current as a function of output current.

$$I_{in}V_{in} = I_{out}V_{out}, I_{L1}V_{in} = I_{L2}V_{out}, I_{L1} = I_{L2} \frac{V_{out}}{V_{in}} \quad (8)$$

If the equation (8) is substituted into equation (7), the switch peak current is defined as follows:

$$I_{switch(peak)} = I_{out} \frac{V_{out} + V_{in}}{V_{in}} + \frac{\Delta i_{L1}}{2} + \frac{\Delta i_{L2}}{2} \quad (9)$$

Finally, the output current can be written as a function of switch peak current and other known parameters in the circuit as in equation (10).

$$I_{out} = \frac{V_{in}}{V_{out} + V_{in}} \left[ I_{switch(peak)} - \frac{V_{in}D}{2L_1f_s} - \frac{V_{out}(1-D)}{2L_2f_s} \right] \quad (10)$$

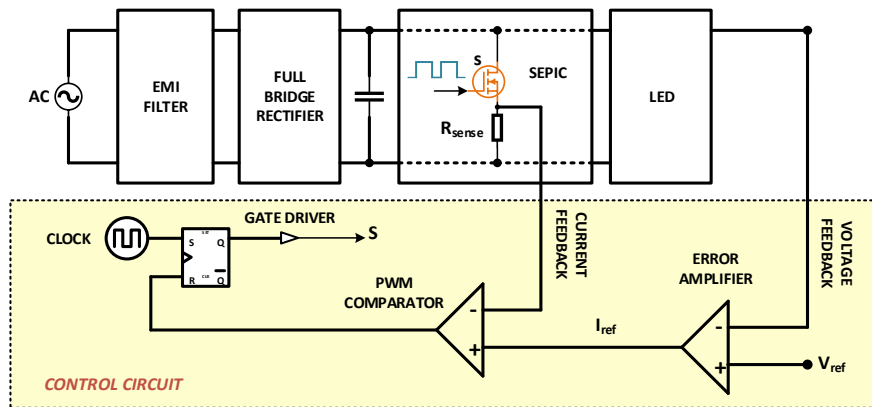


Figure 4. Peak-current-mode-controlled SEPIC LED driver.

Low cost current mode controller UC3842 IC can be used for peak current mode control. This IC can provide a robust control. For current sensing and limiting, related internal structure of the UC3842 IC is presented in Figure 5.

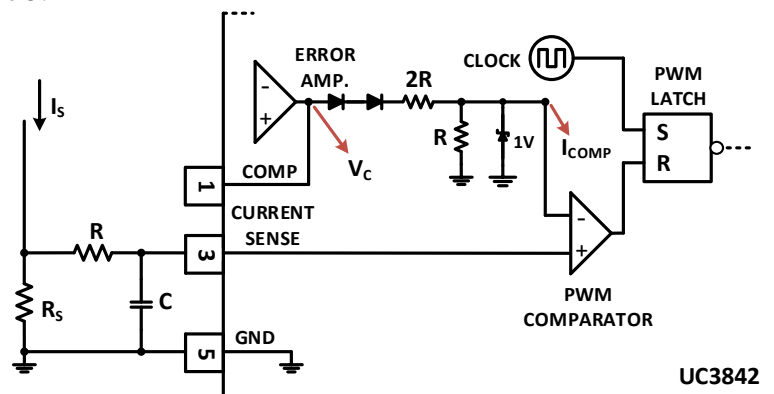


Figure 5. Current sensing and limiting [20].

Error amplifier output voltage is also called as control voltage  $V_c$  which is followed by two diodes, two resistors and a zener diode in Figure 5. The diode pair has a total forward voltage of 1.4 V. The voltage

at the inverting leg of the PWM comparator  $I_{COMP}$  will be equal to the voltage across the resistor R, which is 1/3 of the voltage after the diode's voltage drop from  $V_C$ . So, the peak voltage across  $R_{SENSE}$  is controlled by the E/A output, according to formula [20]:

$$V_{R_{SENSE}}(PEAK) = \frac{V_C - 1.4V}{3} \quad (11)$$

The zener diode limits this peak voltage to 1V [20,21]. Applying the Ohm's law, peak current on  $R_{SENSE}$  can be calculated according to formula:

$$I_{R_{SENSE}}(PEAK) = \frac{V_{R_{SENSE}}(PEAK)}{R_{SENSE}} = \frac{V_C - 1.4V}{3R_{SENSE}} \quad (12)$$

Eventually, when the voltage across  $R_{SENSE}$  reaches its peak value, SR flip-flop will toggle low and MOSFET will turn off. Cycle-by-cycle control will be achieved.

In this study, a variable DC voltage source as control input voltage is used to adjust output current, brightness of the LED. As the control voltage  $V_C$  is decreases, peak voltage across the  $R_S$  will be decreased. Smaller peak voltages will push the MOSFET turn off earlier, and will result in smaller duty cycles. Therefore, the output current can be regulated by adjusting  $V_C$  properly. Outer feedback loop will be disabled because of the  $V_C$  is controlled by an external dc voltage source. Normally, the voltage feedback is used for overvoltage protection. But in the proposed control strategy, amount of the current flowing through the LED string naturally determines the output voltage and prevents overvoltage. In addition, to prevent huge spikes in current waveform while sensing the current, simple RC filter is used [20, 21]. The proposed control strategy without PFC and with PFC are shown in Figures 6 and 7, respectively.

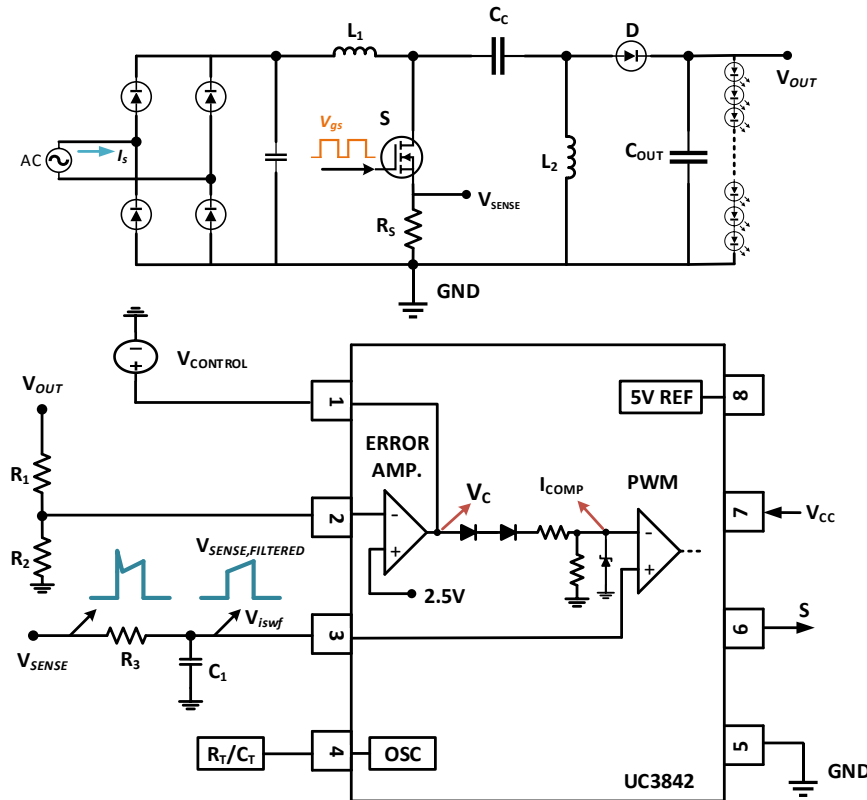


Figure 6. Proposed Peak-Current-Mode Controlled SEPIC LED Driver without PFC.

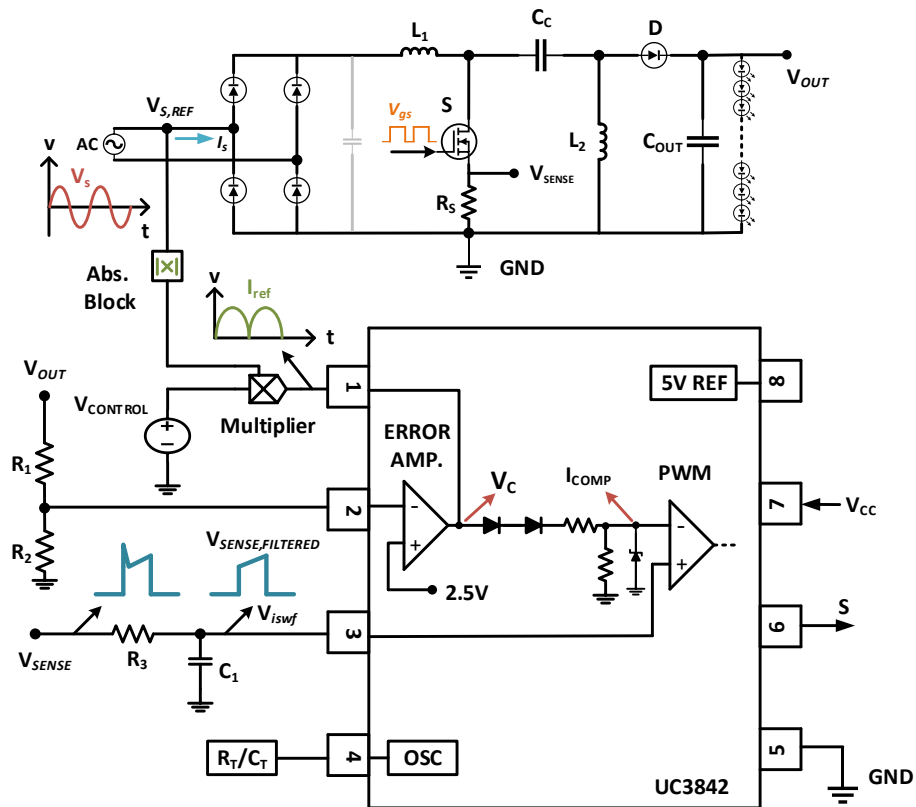


Figure 7. Proposed Peak-Current-Mode Controlled SEPIC LED Driver with PFC.

#### 4. SIMULATION RESULTS AND DISCUSSION

In PSIM simulation, the proposed peak current mode control strategy is applied to the LED driver circuit with PFC and without PFC. For both circuit, current is sensed through a resistor in series with MOSFET, a simple RC filter is used to prevent huge spikes in current waveform while sensing the current, oscillator  $R_T/C_T$  is arranged that 100 kHz switching frequency is obtained, and 220 V(rms)-50 Hz AC main is used as input. The driver circuit without controller is shown in Figure 8. Controllers are provided in related sections.

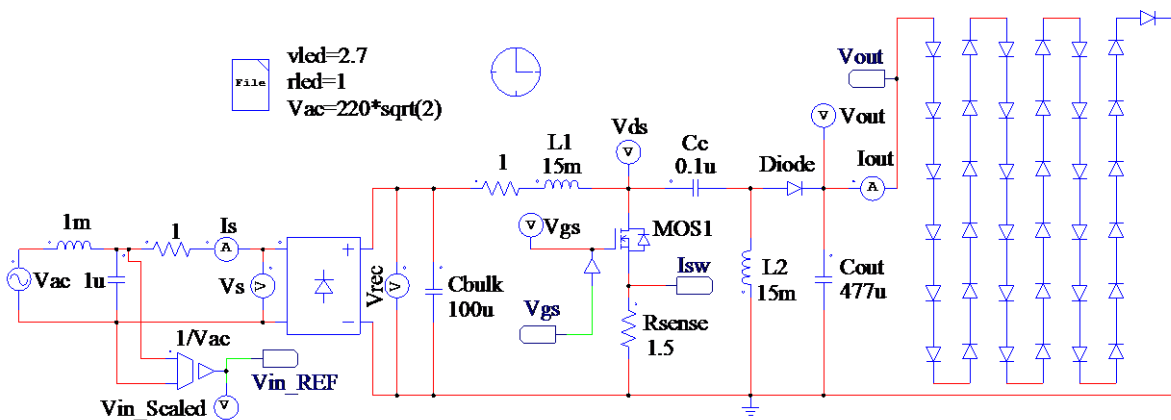


Figure 8. PSIM driver circuit without controller.



#### 4.1. Without PFC

The controller circuit without PFC is shown in Figure 9. In proposed control strategy, a variable dc voltage source is directly connected to pin 1 of IC. Therefore, the control input voltage  $V_{CONTROL}$  is the same node as error amplifier output  $V_C$ .

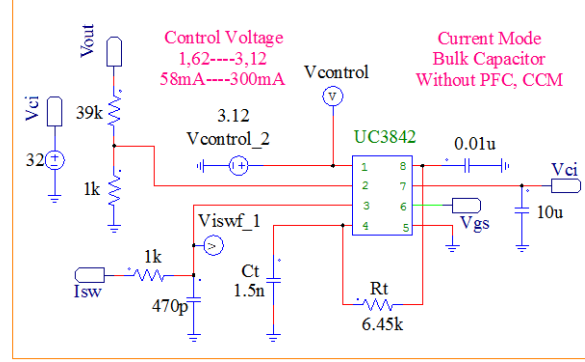


Figure 9. Controller circuit without PFC.

When the control input voltage is 3.12 V, output current will be adjusted 300mA as shown in Figure 10. As can be seen, there is no current flow until the applied voltage reaches 99.9V ( $37 \times 2.7V$ ).

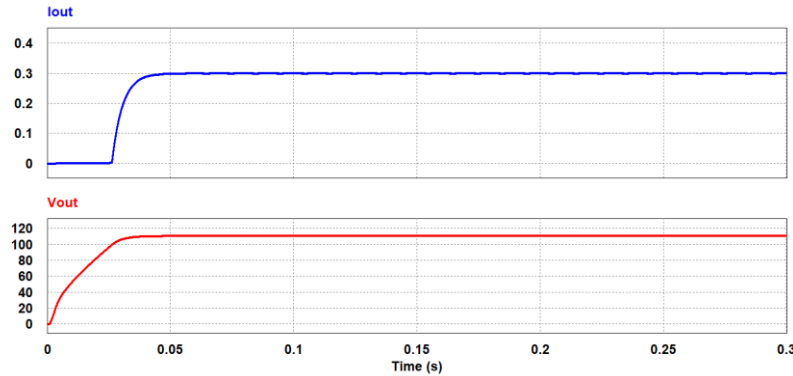


Figure 10. Output current  $I_{OUT}$  (A) and output voltage  $V_{OUT}$  (V) [ $V_C$  at 3.12 V].

Control mechanism and generation of PWM signal are shown in Figure 11. 100 kHz clock signal (red), filtered sensed voltage (red) and peak reference voltage (blue), PWM signal (black) are shown, respectively. Clearly,  $V_{gs}$  turned from 1 to 0 when the sensed voltage reaches the peak reference voltage.  $V_{gs}$  is applied to MOSFET gate-source, to switch MOSFET on and off. Furthermore, RC filter has a significant influence on sensed voltage. It smooths the operation when voltage starts to increase and does not allow undesirable effects on gate signal. In Figure 11, peak reference voltage is limited to 0.64V, which can be calculated by formula (11):

$$V_{R_{SENSE}}(PEAK) = \frac{3.12 - 1.2}{3} = 0.64V \quad (13)$$

Where,  $R_{SENSE}$  is chosen as 1.5  $\Omega$ , two diode voltage drops as 1.2 V.

Peak current on  $R_{SENSE}$  is limited to 0.426A, which can be calculated by the formula (12):

$$I_{R_{SENSE}}(PEAK) = \frac{0.64V}{1.5\Omega} = 0.426 A \quad (14)$$

In Figure 12, the peak current on  $R_{SENSE}$  is a bit higher than the expected value which is 0.455 A. However, equation (9) gives the switch peak current nearly to this value as follows:

$$I_{switch(peak)} = 0.3 \frac{111 + 306}{306} + \frac{0.048}{2} + \frac{0.048}{2} = 0.456 \text{ A} \quad (15)$$

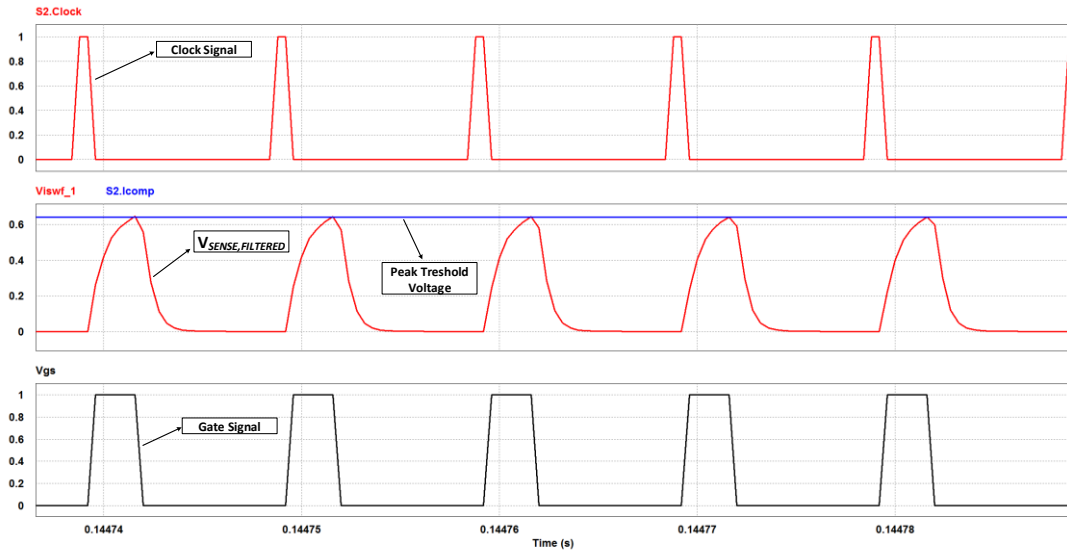


Figure 11. Couple of PWM cycles ( $V_c$  at 3.12 V).

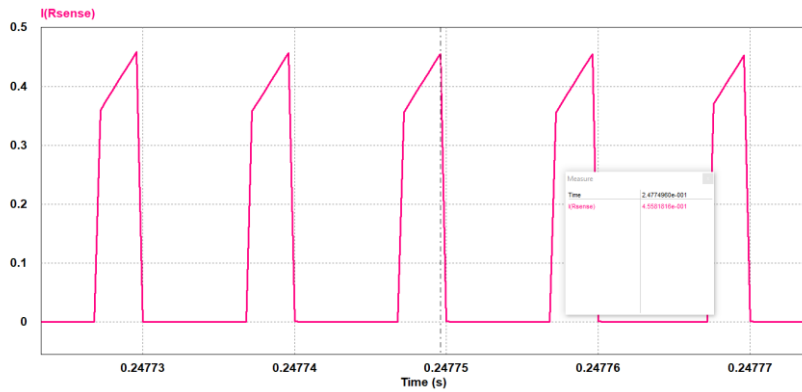


Figure 12. Peak current on  $R_{SENSE}$  ( $V_c$  at 3.12 V).

Very poor power factor around 0.22 is obtained in the line as shown in Figure 13. The line current THD is obtained as 213% for driver circuit without PFC at 300 mA output current.

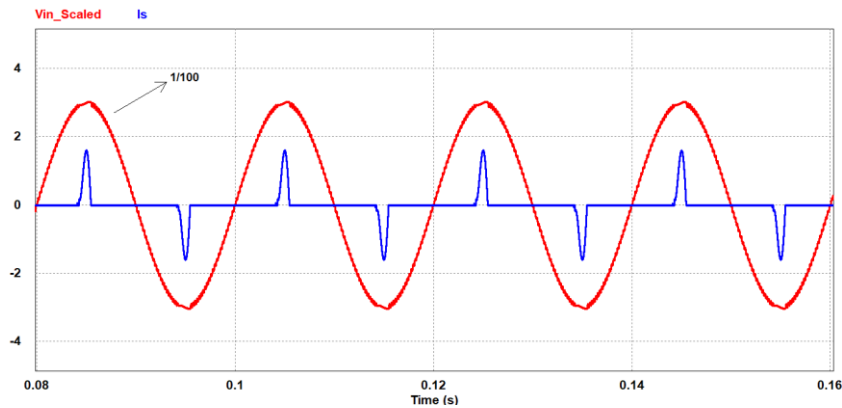
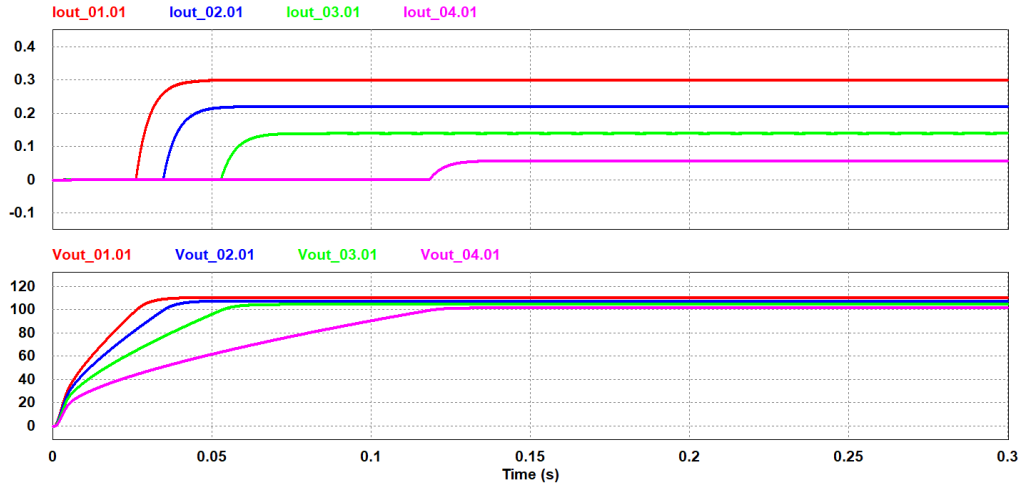


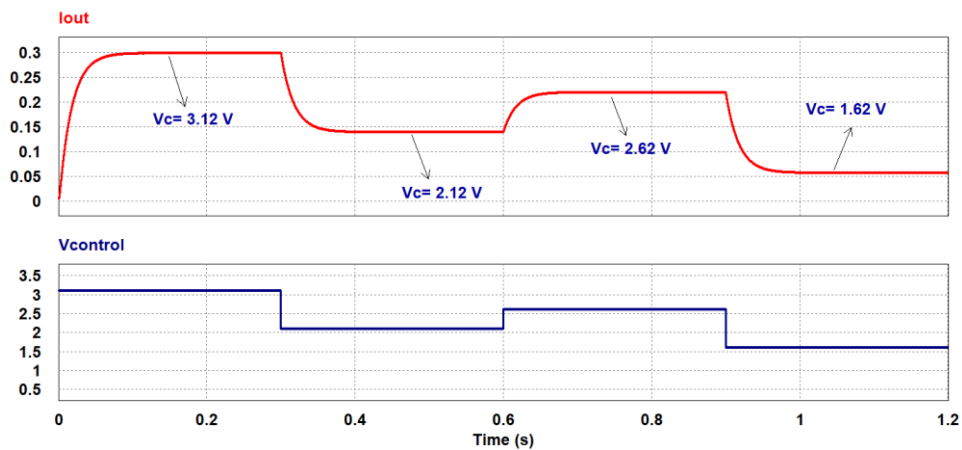
Figure 13. Poor power factor ( $V_c$  at 3.12 V).

Four different control input voltage  $V_{CONTROL}$  levels are selected to adjust the output current.  $V_{CONTROL}$  was initially 3.12 V. Then, it is decreased by 0.5 V at each step. The output current results in 300mA, 221mA, 140mA and 58mA, respectively as shown in Figure 14.



**Figure 14.** Output currents (A) and voltages (V) [ $V_{CONTROL}$  at 3.12V (Red), 2.62V (Blue), 2.12V(Green) and 1.62V(Pink)].

Hence, the output current is adjusted around 50mA-300mA by changing the control voltage. LED brightness control is achieved. But, even more bad power factors (below 0.22) are obtained as the output current decreases. The output voltage is also decreased regarding the internal resistances of series connected LED's. 111 V peak, around 102 V minimum output voltages are obtained. Moreover,  $V_c$  is randomly changed to adjust output current in every 0.3 second while the circuit is running as shown in Figure 15.



**Figure 15.** Output current adjustment.

#### 4.2. With PFC

The controller circuit with PFC is shown in Figure 16. In proposed control strategy, the control input voltage  $V_{CONTROL}$  is multiplied by sinusoidal input voltage and connected to pin 1 of IC. Now, the control voltage node  $V_c$  denotes as  $I_{ref}$ . The reference current  $I_{ref}$  is forced to follow the line current in

order to get high power factor. Additionally, the bulk capacitor at the input of the converter is replaced with a small capacitor (100nF).

Four different control input voltage  $V_{CONTROL}$  levels are selected.  $V_{CONTROL}$  was initially 6 V. Then, it is decreased by 1 V at each step. The output current results in 305mA, 279mA, 220mA and 130mA, respectively as shown in Figure 17. Likewise,  $V_{CONTROL}$  is randomly changed to adjust output current in every 0.3 second while the circuit is running as shown in Figure 18.

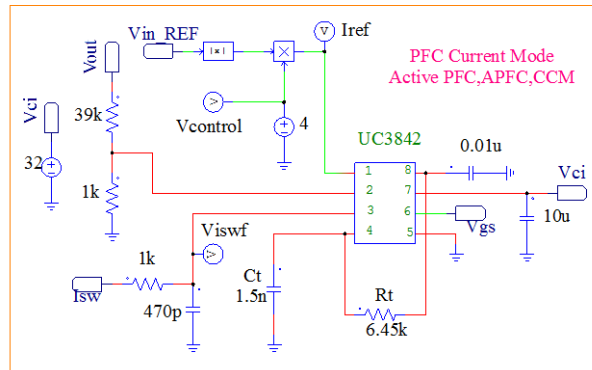


Figure 16. Controller circuit with PFC.

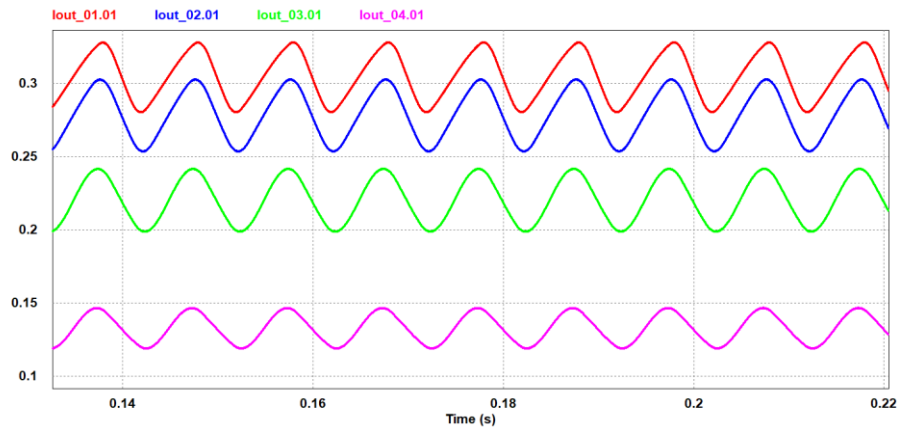


Figure 17. Output currents (A) [ $V_{CONTROL}$  at 6V(Red), 5V (Blue), 4V(Green) and 3V(Pink)].

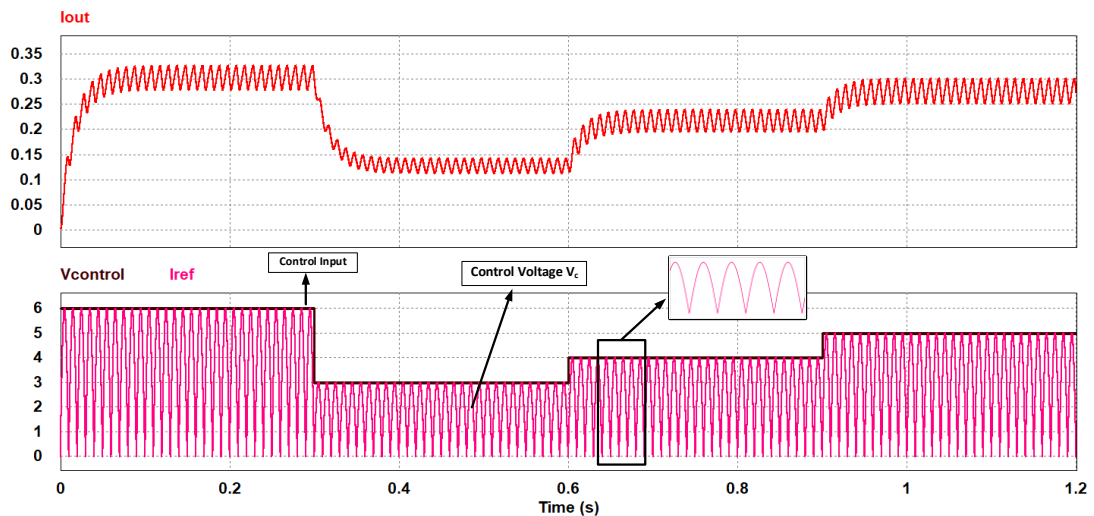


Figure 18. Output current adjustment in PFC driver.

The output current ripple is obtained around 16%, while the output voltage ripple is 2V. The ripple frequency is twice the line frequency. The line current is always nearly in phase with the line voltage as shown in Figure 19 while adjusting the desired output current level. The line current THD is obtained as 25% for driver circuit with PFC at 305 mA output current.

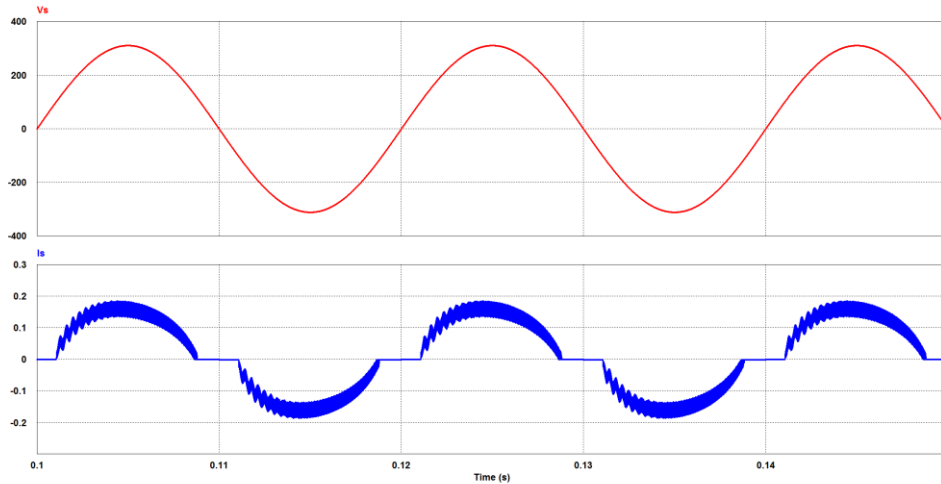


Figure 19. Input voltage  $V_S$  and input current  $I_S$  ( $V_{CONTROL}$  at 4V).

However, the control input voltage is adjusted to 6V to operate at 305 mA output current. When the control input voltage is multiplied by the input voltage, the reference current  $I_{ref}$  waveform is shaped like full wave rectified voltage having 6 V peak as shown in Figure 20.

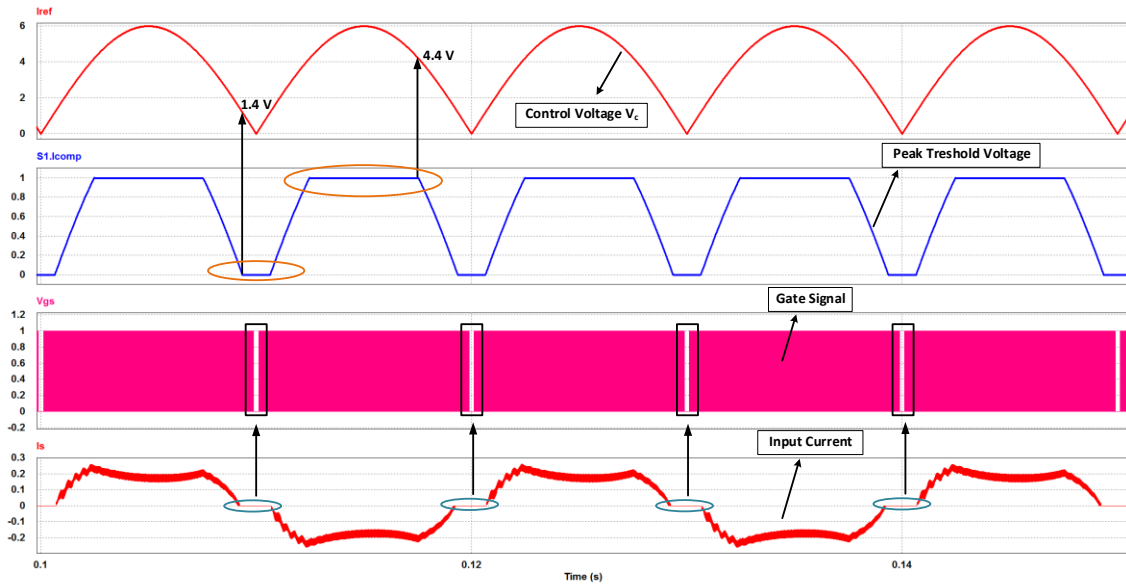


Figure 20. Distorted input current due to control voltage limitations on IC ( $V_{CONTROL}$  at 6V).

According to formula (11), minimum control voltage should be greater than 1.4V. So, the control voltage smaller than 1.4V will cause small blank areas on gate signal  $V_{gs}$  of MOSFET in each half period of input voltage (10ms). Also, peak threshold voltage is limited to 1V with a zener diode. Therefore, providing that the control voltage is greater than 4.4V, the reference voltage will not exceed 1V. Eventually, the input current waveform  $I_S$  is slightly distorted in these areas.

### 4.3. Comparison

The output current of the LED is successfully controlled by both circuits. High power factor is achieved with power factor correction LED driver. The output current level of the LED versus power factor is plotted in Figure 21.

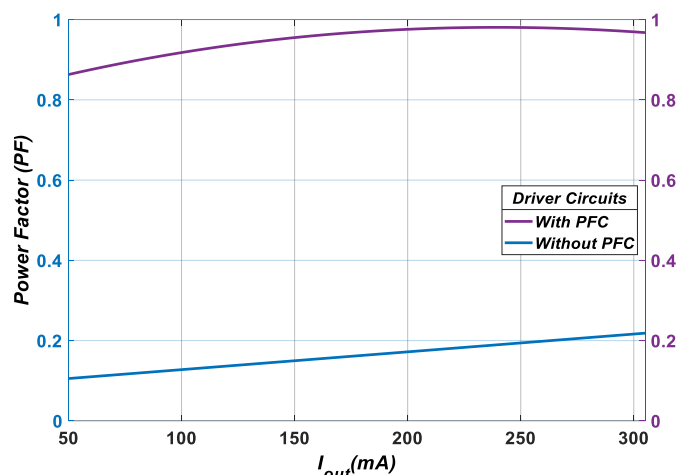


Figure 21. Output current vs. Power Factor.

While operating at nearly 300 mA output current, THD values are obtained as 213% and 25%, for without PFC and with PFC driver circuits, respectively. When the line current THDs of two circuits are compared for nominal output current, the driver circuit with PFC has 8.5 times lower THD value than driver circuit without PFC.

Moreover, flicker tests for LED string are held for both circuits in Figure 22 and 23 where percent flicker and flicker index are measured and calculated by following formulas [8]:

$$\text{Percent Flicker or Mod\%} = 100 \frac{I_{MAX} - I_{MIN}}{I_{MAX} + I_{MIN}} \quad (16)$$

Where,  $I_{MAX}$  is the maximum output current, while  $I_{MIN}$  is the minimum output current.

$$\text{Flicker Index} = \frac{\text{Area 1}}{\text{Area 1} + \text{Area 2}} \quad (17)$$

Where, Area 1 is the area above the averaged output current, while (Area 1 + Area 2) is the total area of the output current curve.

According to [8], low risk region for flicker frequencies above 90 Hz is given by " $\text{Mod\%} < 0.08f_{flicker}$ ", while no observable effect level (NOEL) is given by " $\text{Mod\%} < 0.0333f_{flicker}$ ". In our case, modulation in current waveform should be smaller than 8% for low risk level and smaller than 3.33% for NOEL, considering flicker frequency is 100 Hz. It can be seen from Figure 23, the modulation also called as percent flicker stays in the limits of NOEL for different output current levels. However, the modulation in PFC circuit stays in low risk level for nominal operation current 300 mA, while the modulation for below 300 mA output current exceeds the limits for low risk level up to 10.5%.

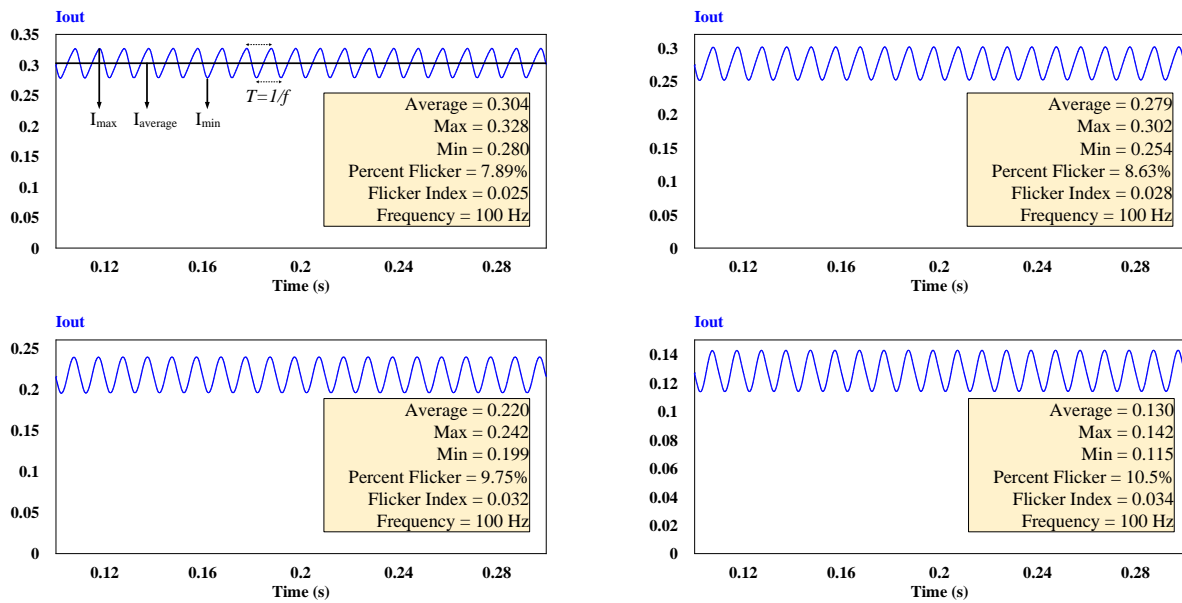


Figure 22. Flicker measurements (With PFC).

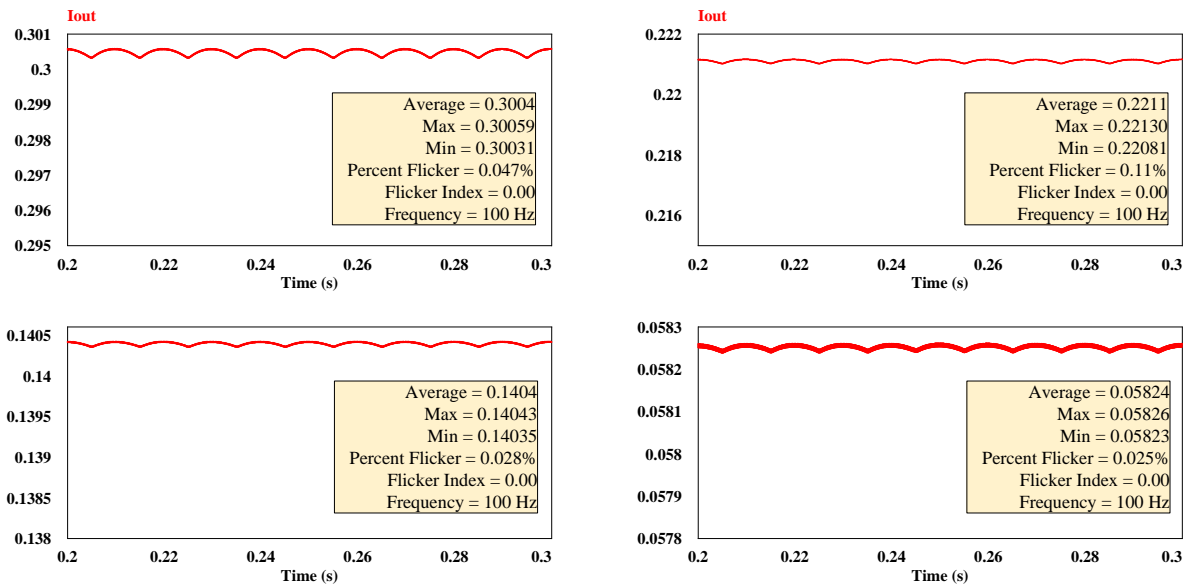


Figure 23. Flicker measurements (Without PFC).

## 5. CONCLUSION

In this study, a peak current mode control strategy presented here is proposed to control LED brightness. SEPIC converter that operates in continuous conduction mode is chosen as LED driver. The output current of the SEPIC converter is adjusted by changing peak threshold voltage value. A low-cost IC chip is used for the proposed control strategy.

Driver circuit without PFC is mainly focused on a robust output current control from 50mA up to 300 mA. But, the power factor is significantly low because of the input capacitor filter. Also, the driver circuit suffers from this bulk capacitor which increases the volume of the driver and cost. On the other hand, flicker on LED lamps is very low at no observable effect level meaning that no health risk is concerned.

Driver circuit with PFC aims to improve power factor. Bulk capacitor at the input is removed. Output current control from 90 mA up to 300 mA is held. The output current and voltage ripple are higher than in the first circuit but kept within acceptable levels. However, high power factor is obtained in all operation region. The highest power factor is recorded as 97.97% when the output current is 279 mA. Unfortunately, the percent flicker on LED is slightly higher than the limits for low risk level while operating below 300 mA. According to our findings, output capacitor filter can be enlarged to reduce output current ripple which leads to reduction of the percent flicker.

LED driver circuits have become much important by the increasing demand on LED technology. Therefore, the driver circuit design is an essential task. The SEPIC driver circuit by the proposed control strategy in this study offers LED brightness control for the consumer comfort, high power factor for the energy efficiency and low flicker limits for human health.

## **CONFLICT OF INTEREST**

The authors stated that there are no conflicts of interest regarding the publication of this article.

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