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Driver Design and Simulation for 6W LED Bulb with PWM Dimming

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Abstract

The growing awareness of the need to reduce energy cost has increased the popularity of Light Emitting Diodes (LED). Today, LED's claim to have more than 120 lumens/watt efficacy, more than 50,000 hours life time and compact size, making them replace conventional lighting. Applications such as residential and commercial lighting require thousands of lumens, creating a need to drive LED strings. LED works on DC power and therefore it requires a device that can convert incoming AC power to DC voltage and regulate the current flowing through the LED during its operation. If the current exceeds manufacturer recommendations, LED's become brighter but their light output degrades due to the junction temperature rise and this may reduce the useful life of LED. Since LED's are very fast devices, if there is any variations in forward voltage, even for very short time, it will cause big variation in current which may damage the LED. In order to avoid these problems and to protect LED from line voltage fluctuations, a proper driver circuit is needed. In this paper the design of driver circuit for a 6W LED bulb with PWM dimming capability with a buck converter is described. The simulation of the driver circuit done in LT Spice and Proteus and the obtained results were also explained in this paper.

Keywords- *Driver circuit, Efficacy, Junction temperature, Light emitting Diodes, Line voltage fluctuations, LT Spice, Lumens, Proteus*

I. INTRODUCTION

As about 20% of total electricity in the world is consumed for lighting applications, there is a demand for high efficiency lamps. Nowadays, high-power light-emitting diodes (LED's) have become an important competitor for traditional light sources for various applications, such as home and office lighting, automotive lights and traffic lights as they consume less energy than incandescent and fluorescent lamps. The LED's used for lighting purpose are power LED's which are 1-3 W rated devices usually run at 350mA. LED is basically a PN junction diode which works on the principle of electroluminescence. That is, when a voltage is applied across the diode, electrons from the conduction band recombines with the holes from the valence band releasing energy in the form of photons. The recombination can be direct or indirect recombination. The colour of the emitted light depends on the energy band gap of the semiconductor.

LED is a constant voltage load with low Equivalent Series Resistance (ESR)[1]. As LED is a device that emits light when electrically biased and is similar to standard diodes, most of the electrical characteristics of LED matches with that of diodes. As shown in the V-I characteristics (Fig 1), any further increase in voltage after reaching the threshold voltage of LED, will lead to rapid increase in current through them. Because of this behavior it is better to drive an LED with constant current rather than constant voltage. As the current through the LED increases, its luminous flux also increases. Thus the current through LED is a key parameter that determines the intensity,colour and forward voltage of light emitted from the LED.

LED works on DC power and therefore it requires a device that can convert incoming AC power to DC voltage and regulate the current flowing through the LED during its operation. From V-I characteristics it's clear that slight variations in supply voltage can cause very large change in current. If the current exceeds manufacturer recommendations, LED's become brighter but their light output degrades due to the junction temperature rise and this may reduce the useful life of LED. Also as LED is turned on for more time its junction temperature increases with time[2]. Since LED's are very fast devices, if there is any variations in forward voltage, even for very short time, it will cause big variation in current which may damage the LED. In order to avoid these problems and to protect LED from line voltage fluctuations, LED's must be driven from a current source. Without an appropriate driver circuit LED's may become too hot and unstable, leading to poor performance or failure of LED lights. Thus like the use of ballast for fluorescent lamp, driver circuit is used for LED lights to provide correct power supply to function and perform at their best.

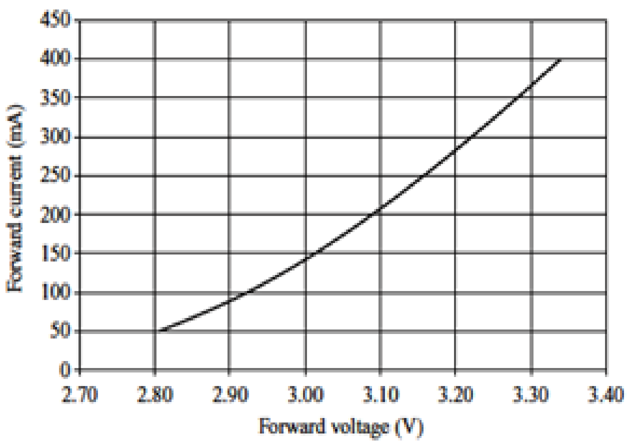

Figure 1. VI Characteristics of power LED

Mainly LED drivers consist of rectifier and a DC to DC converter circuit. Driver IC's were also available in the market. The power factor, harmonic distortion etc. of an LED light depends on the LED driver used. LED's with power factor greater than 0.98 are available in the market whereas the power factor for CFL lights are usually below 0.7. Since converter circuits such as buck converter, boost converter etc. were used it is possible to control the light output by using switches like MOSFET in the converter circuit by giving appropriate gate signals. Some of the applications of LED lighting requires simple ON and OFF, but a greater number of applications requires dimming the output between 0 and 100%.

II. BUCK CONVERTER

A buck converter is a specific type of dc-dc power electronic converter whose goal is to efficiently step down DC voltage to a lower level with minimal ripple. In a buck converter circuit, a power Metal Oxide Field Effect Transistor (MOSFET) is usually used to switch the supply voltage across an inductor and a load connected in series[3]. The inductor is used to store energy when the MOSFET is turned on; this energy is then used to provide current for the load when the MOSFET is turned off. A diode across the load and inductor circuit provides a return path for the current during the MOSFET off time. A simple schematic is shown in Fig 2(a).

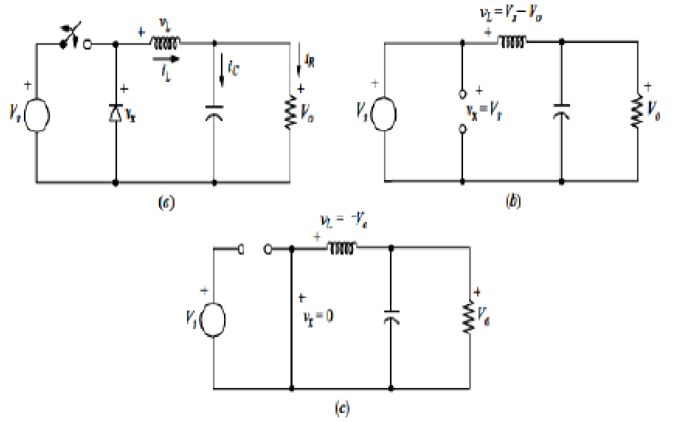

Figure 2. (a) Buck dc-dc converter (b) Equivalent circuit for the switch closed (c) Equivalent circuit for the switch open

If the low-pass filter is ideal, the output voltage is the average of the input voltage to the filter. The input to the filter is `Vs' when the switch is closed and is zero when the switch is open, provided that the inductor current remains positive, keeping the diode on. If the switch is closed periodically at a duty ratio `D', the average voltage at the filter input is `VsD'. This analysis assumes that the diode remains forward-biased for the entire time when the switch is open, implying that the inductor current remains positive leading to continuous current mode.

When the switch is closed in the buck converter circuit of Fig 2(a), the diode is reverse-biased and Fig 2(b) is an equivalent circuit. The voltage across the inductor is,

$$V_L = V_s - V_0 = L\frac{di}{dt} \qquad (1)$$

When the switch is open, the diode becomes forward-biased to carry the inductor current and the equivalent circuit of Fig 2(c) applies. The voltage across the inductor when the switch is open is,

$$V_L = -V_0 = -L\frac{di_L}{dt} \qquad (2)$$

III. DIMMIMG METHODS

The capability of reducing the intensity of output light is called dimming. Semiconductor LED's have a non-linear relationship between current and voltage, unlike that of a resistor in which the current and voltage change linearly. If the voltage supplied to an LED is varied even by a small amount, the current or effective light output of the LED changes significantly, resulting in difficulty achieving precise control of light output. Conversely, small changes in current result in small light output changes. Therefore, a current-controlled method is a preferred way to drive LED's. So LED's can be dimmed by controlling the forward current owing through them. Dimming white light LED systems can be accomplished by two techniques: Continuous Current Reduction (CCR) and Pulse Width Modulation(PWM). The main difference between the two dimming methods is that the first one imposes a linear variation of the value of the continuous current amplitude, while in PWM methods, the current imposed to the LED is a rectangular wave with varied duty cycle. The two waveforms used in dimming are shown in Fig 3. In both cases the average current supplied to the LED is the same, 50% of current nominal[4].

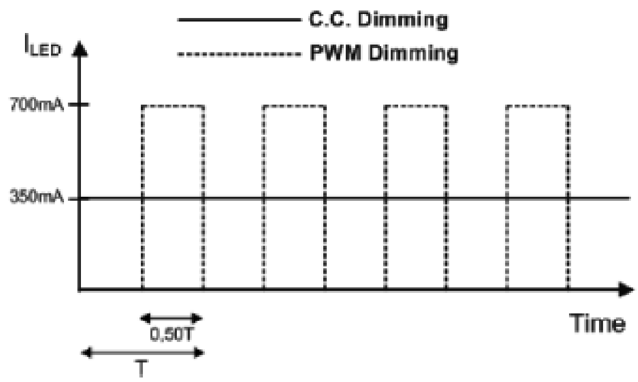

Figure 3. Waveforms of current in the LED by the two dimming methods

Continuous current reduction is a method in which the decrease in current causes the decrease in light output. This type of dimming is also referred to as Analog Dimming. In this method the dc current owing through the LED is controlled to achieve dimming. Supplying more current to an LED increases the light intensity, and reducing the current decreases its intensity. Typically, the current is controlled using a resistor in series with the LED (a variable resistor like a potentiometer) or a current regulator circuit. With this method, dimming in the range from 100% to 10% of maximum is achievable (dimming below 10% is difficult) and offers a simple and cost effective means of dimming LED's. CCR dimming works well for a single LED device. However, for a string of LED's which are driven with their recommended forward currents, a reduction in current may turn off some LED's before others, and dim some of them while keeping others still quite bright due to variation in the characteristics of the different LED's. Furthermore, this might lead to spectral slide, i.e., change in color of the lighting. This is because changing the value of current owing through the LED affects the wavelength of light emitted[5]. Also changing the operating current linearly, as done with CCR, may not result in a linear change in light

output. So CCR dimming is suitable for applications that may have strict EMI requirements, such as medical suites and high motion activity or rotating machinery.
A more efficient way of dimming LED's is to use the PMW dimming. In PWM dimming, the LED's are supplied by pulse currents at high frequencies varying between the recommended forward current (for maximum brightness) and zero. The LED's turn on when the current is high and turn off when the current is zero. In this technique, the frequency of the current is high enough to ensure that the turning on and off of the LED's are not apparent to the eye and it is outside the audible range to avoid any acoustic issues. With PWM, the strings of LED bulbs can all be driven with the recommended forward current when turned on. Dimming can be achieved by tuning the duty ratio of the current supplied to the LED's. The higher the duty ratio is, the brighter the LED will appear to the observer due to higher average forward current being supplied to the LED. The average current for duty cycle D would be related to the peak current[6] by

$$I_{avg} = I_{peak} \times D \tag{3}$$

The peak current would depend on the nature of the load and the supply voltage. The switching period, T, should be small enough so that no visual flicker would occur.

IV. LED DRIVER DESIGN

LED's are current-driven source whose brightness is proportional to their forward current. To ensure that constant current is delivered to each LED in an array, the power topology must be able to deliver an output voltage equal to the sum of the maximum forward voltages of every device placed in the string at constant current. For designing 6W LED bulb, the data's of Edison C series 1W cool white LED's are selected. To form 6W six such 1W LED's are arranged in series parallel connection such that three 1W LED's are connected in series and two such branches are connected in parallel. Each 1W Edison LED is having a forward voltage of 3.4V. Thus here the output voltage is 10.2V, so an input of 12V DC is chosen. Since the output is less than the input a buck converter is to be designed as follows:

Input voltage, Vs = 12V

Output voltage across string of LED's, V0= 3×3.2V = 10.2V

Output current through the string of LED's, I_0 = 2×350mA
= 700mA

Output voltage ripple, $\frac{\Delta V_0}{V_0} = 10\%$

Switching frequency, f_s = 25kHz

Higher the switching frequency, smaller will be the size of the inductor and more robust will be the design. But a very high switching frequency can lead to more switching losses. Also PWM switching should be greater than 100 Hz so the human eye does not perceive flicker. Hence the value of switching frequency is fixed at 25KHz.

$$\text{Time period; } T = 1/f_s = 40\mu s \tag{4}$$

$$\text{Duty Cycle, } D = Vo/Vs = 10.2/\ 12 = 0.85 \tag{5}$$

Inductor current at boundary condition, $I_{LB}=I_{OB}= P_0/V_0$ = 6/10.2 = 0.588A (6)

$$\text{Inductance, } L \geq \frac{DT(V_s - V_0)}{2I_{OB}} \tag{7}$$

$$\geq \frac{0.85 \times 40 \times 10^{-6}(12 - 10.2)}{2 \times 0.588}$$

$$\geq 52.04\mu H \approx' 53\mu H$$

$$\text{Capacitance, } C \leq \frac{T^2(1-D)}{8L(\frac{\Delta V_0}{V_0})} \tag{8}$$

$$\leq \frac{(40 \times 10^{-6})^2 (1 - 0.85)}{8 \times 52.04 \times 10^{-6} \times 0.01}$$

$$\leq 5.76\ \mu F \approx 6\mu F$$

4.1.Choice of MOSFET

Peak voltage seen by MOSFET is equal to maximum input voltage.

Using 50% safety rating, V_{DS} = 1.5× √2 × 12 = 25.45V

Maximum current through MOSFET, $I_{MOSFET} = I_0 \times \sqrt{D}$ = 0.645A (9)

A MOSFET with three times the current is chosen to reduce the losses ie. 1.93A.

4.2. Diode selection

When selecting a diode, one must consider the forward voltage drop, breakdown voltage, average forward current, and maximum power dissipation. Hence, a device with a forward drop as low as possible is chosen. The forward voltage drop will increase greatly with increasing forward current. A higher for ward voltage drop will cause greater power dissipation in the device. This, in turn, will decrease converter efficiency and may overheat the diode. The diode's breakdown voltage should be rated above the voltages in the system. The forward current rating should be greater than the designed rms current for the circuit's inductor.

$$\text{Diode Current, } I_D = (1-D)I_0 = (1-0.85)\times 0.7 = 0.105A \tag{10}$$

Maximum reverse voltage should be V_s=12 V

V. SIMULATION AND RESULTS

Here the deigned 6W buck converter LED driver circuit is simulated using LT Spice and Proteus. For simulation purpose six Edison C series 1W LED's were selected. The characteristics of Edison LED obtained from datasheet are shown in Table 1.

Table 1. LED parameters from Edison C series datasheet

Parameter	Value
DC Forward Current	350mA
Reverse Voltage	5V
Forward voltage	3.4V
Drive Voltage	5V
Viewing Angle	130˚
Thermal Resistance	10˚C/W
Max. Luminous Flux @ 350mA	130 lm
Colour	Cool white
LED Junction Temperature	125˚C
CRI	68

5.1.Open loop buck converter in LT Spice

The simulation model of a buck converter is shown in Fig 4. The simulation was done in LTSpice version 4.22. The purpose of buck converter is to maintain constant current across the LED string. To modify the V-I characteristics according to the Edixeon C series as gathered from the datasheet, the Spice Directive was added to change the characteristics of the LED used. Thus the LED's are imported into LTSpice library by using there corresponding spice files.

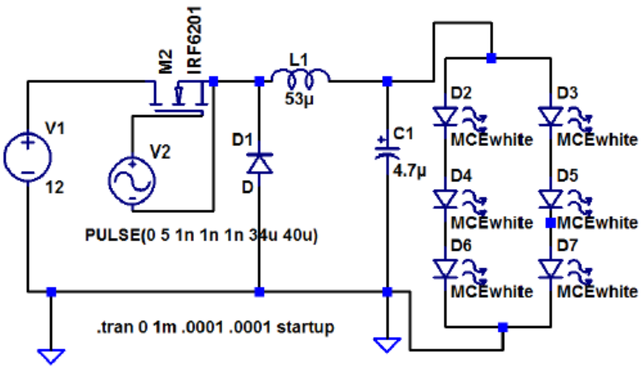

Figure 4. Simulation of LED driver circuit in LTSpice

Analysis of buck converter is performed in continuous mode of operation with duty cycle D = 0.85, Switching frequency, fs = 25KHz. The components included in the model of buck converter are inductance, L= 53µH and capacitance, C = 4.7µF. Input voltage of 12V DC is applied to the buck converter and the gate of the MOSFET is given a PWM signal of duty ratio 0.85 and 12 V using a pulse generator. The simulation time is set as 1ms.

Fig 5. shows the current through each LED in the string. Since all the 6 LED's are of same characteristics the current through each LED is same as shown in the waveform. Average current of about 350.5mA is passing through each LED.

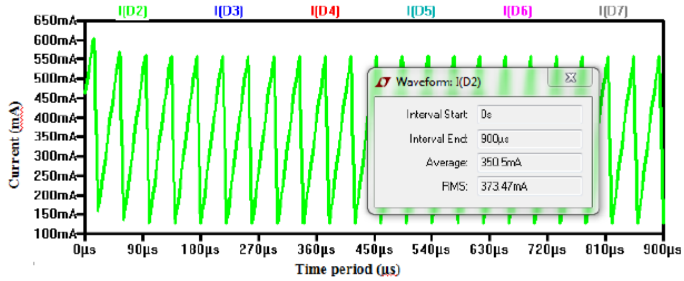

Figure 5. Current through each LED in LTSpice

Fig 6. shows the output voltage across the LED string which is about 9.57V. The variation of voltage and current from high to low is because of the On and Off of the MOSFET switch according to the PWM signal.

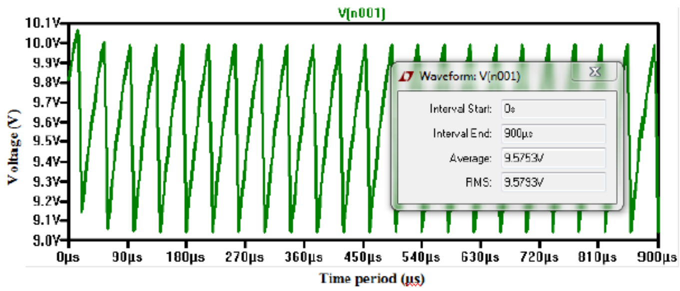

Figure 6. Output voltage of LED driver circuit in LTSpice

5.2.LED driver circuit with output voltage control in proteus

In Proteus, software programs can be written to run the existing sample design for evaluation. Here the simulations were done in Proteus 8 Professional. In LTSpice, microcontrollers are not present in library files where as in Proteus it is available. Here instead of LED string, corresponding resistive load having the equivalent dynamic resistance of the series parallel LED string is placed. An N-channel MOSFET IRF640NS is used as the switch. PWM signals are generated from the microcontroller. PIC 16F877A microcontroller is used here and the PWM output is taken from its 17th pin. The program for generating PWM is written in mikroC PRO for PIC(version 6.4.0) and the hex file is generated. This hex file is loaded in PIC16F877A.

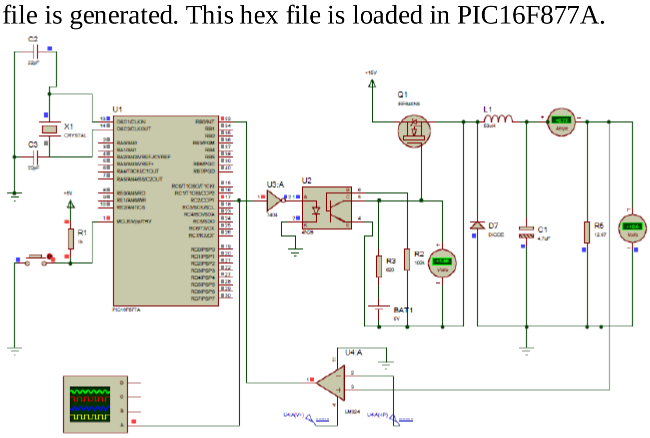

Figure 7. LED driver circuit with output voltage control in proteus

The pulse from the microcontroller is just 5V, so, in order to amplify it we are using the driver circuit. A driver circuit is used to provide 9 to 20 volts to switch the MOSFET switches of the inverter. The control pulse from the microcontroller is in the range of 5 volts and is fed to the gate terminal of an npn transistor, which together forms the driver circuit part. Whenever the control pulses become positive, the npn transistor turn on and conducts the voltage applied to its collector terminal. This signal is fed as the gate control signal for the switches of the inverter. Thus the driver circuit amplifies the low voltage signal coming from the microcontroller. Also the driver circuit consists of an optoisolatar for isolating the power circuit part and the control (PIC) circuit part, so that MOSFET switches can be prevented from damage. Here the output voltage obtained is about 10 V and the current through 6W string is about 0.71A.

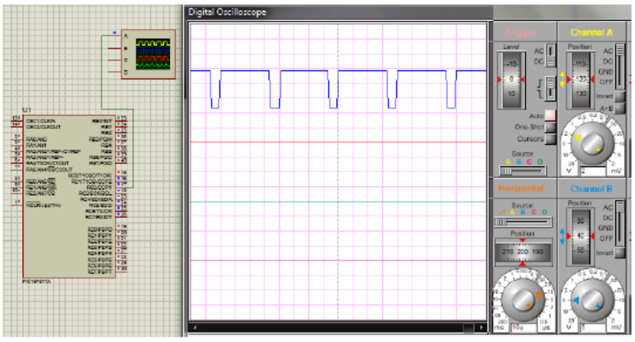

Figure 8. PWM generated from PIC at 85% duty cycle in proteus

The output is taken and is compared with a reference voltage of 10.2V in a comparator LM324 and the resultant high or low signal is given to the pin number 33 of the PIC. In PIC if PWM is generated with reduced duty cycle if the output voltage is higher than the reference voltage. Thus the output voltage is controlled with the help of a comparator. Fig 8. shows the PWM generated from PIC at 85% duty cycle. At 85% duty cycle the MOSFET will be on for 34µs and off for 6µs. An output voltage of about 10.5V and a current of 750mA were obtained.

VI. Conclusion

Energy savings has now become a key factor for the development of a country. A lot of energy is wasted as conventional lighting systems works on bi-level approach. The DC to DC buck converter which can control the 12V DC supply to 10.2V is developed as the LED driver circuit for 6W LED bulb. The buck converter is designed and simulated using LTSpice and Proteus. The resultant output voltage across the LED from LT Spice is obtained as 9.57V. and current through each LED was 350mA in LTSpice. But the PWM control cannot be implemented in LT Spice. Proteus is real time simulation software and PWM dimming can be implemented using proteus. In proteus the output voltage obtained is about 10 V and the current through 6W string is about 0.71A.

As a future work the hardware of the buck converter 6W LED driver can be developed and the simulation results can be verified.

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