Bilevel Current Driving Technique for LEDs

Muhammad Tariq, Dr.B.N.Sarkar

Abstract— **The two popular driving techniques, used in LED drivers,are amplitude modulation (DC mode) and pulse-width modulation (PWM). The dimming function with PWM driving technique is attractive although lower luminous efficacy and stresses on the LEDs due to pulsating power are the disadvantages in comparison to amplitude mode. This paper introduces a current driving technique to improve the luminous efficacy over the conventional PWM technique while maintaining the dimming capability. This is achieved by introducing a DC-offset into the conventional PWM current waveform. It is found that the luminous efficacy increases with increasing DC-offset while the stresses due to pulsating power are reduced. Implementation and verification of the proposed driving technique using a prototype driver are presented.**

Index Terms— **Bilevel current, buck converter, control, LED, Luminous efficacy.**

List of Principal Symbols:
All the quantities are in p.u. except otherwise stated
v_r: voltage across resistor, R
v_{ext}: External voltage
i : current through LED
I_f: High level PWM current
R : Resistance
D, T, t_{on} : Duty cycle Total time and on-time respectively

I. Introduction

In 1962, the firstred LEDwas made from gallium arsenide phosphorous *(*GaAsP) alloy by N.Holonyak. However both the light output and efficiency were very low and devices were mainly used as indicator lights in small display panels [5]. With the development of new power electronic devices and continuous R & D to find out new materials and architectures, a new form of red emitting LED based on *ALINGAP*/GAP (Aluminum, Indium, Gallium and Phosphorous) that is ten times more efficient than incandescent bulbs. Phosphor on top of the LED to produce a white light .The luminous efficacy of visible LEDs has changed. The different types of light sources require different driving methods. Incandescent light bulb is a light source that can be directly powered by DC or AC voltage[10]. The luminous intensity of the bulb is controlled directly by the supplied power. In general, thyristor-based circuits are used for controlling the conducting period of the AC voltage in order to adjust the power level delivered to the bulbs. Strings of LEDs are normally connected either in series /or parallel or in series-parallel mode to increase the luminous flux for various illumination applications. LED drivers are required to ensure that the high–brightness LEDs operate at appropriate DC voltages and current levels. The converters for driving LEDs are relatively simple to design and more reliable due to less stresses on driver components compared to that for driving gas-discharge lamps. Switch –mode power converters are preferred as LED drivers due to the high efficiency of switching topologies as well as the flexibility of power conversion. There are two main approaches for driving LEDs[2]. One is to control the amplitude of the continuous DC current (i.e. AM driving technique) supplied to LEDs, which can be implemented by current feedback control through the DC-DC converters. Due to easy implementation and low cost of LEDsdrivers with AC input voltage, a rectified sinusoidal current has also been used for driving LEDs for off-line illuminations[12].The AM driving technique has the following disadvantages:

(i) Any change in LED's forward voltage will create a change in the Current flowing through the LEDs. .Thus a slight voltage change will result in variation of luminous intensity..
(ii) Linear voltage regulators cannot step up their input voltages using this technique..
(iii) Low power conversion efficiency results from this driver configuration as efficiency of system depends on input voltage , voltage drop of the LEDs and power dissipation across the linear regulator..
(iv) To vary the luminous intensity of LEDs with Amplitude driving technique, the output current of the driver needs to be continuously adjustable.

II. PULSE WIDTH MODULATION DRIVING TECHNIQUE

This method is used to drive LEDs by using a pulse-width modulation current (ie. PWM driving technique) ,with which the LEDs are powered on and off periodically at high frequencies. The current supplied to the LEDs is controlled by the turn-on time interval per cycle. The PWM driving technique is widely used for display applications since a high control flexibility of luminous intensity and chromaticity can be provided by this method[11]. In this paper a combinatory approach is developed to harvest the relative advantages of the two conventional driving techniques. To retain the colour stability and dimming flexibility, PWM mode is employed to switch the LEDs current between two levels, which forms the dominant current component of the device. To partially compensate for the degradation in the luminous intensity due to duty-cycle averaging in the PWM mode, the lower level of the PWM

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current is raised above zero; hence, the higher current level can be lowered accordingly for a given average current. As the modified PWM current waveform starts to deviate from the simple ON–OFF pulses toward a dc by having the two current levels approaching each other from opposite directions, the detrimental effect of the duty-cycle averaging in simple PWM mode can be gradually compensated and higher luminosity is obtained.

The objectives of electronics driver for LEDs are twofold. First, the driver's output should be matched to the electrical characteristics of the LEDs. Second, the luminous intensity and chromaticity of LEDs should be controlled at desired states. Switch-mode power converters have advantage in terms of output voltage stability and power conversion efficiency. The modified PWM will be referred to as the bilevel current driving technique hereafter in the paper.

In order to control different brightness, an external voltage v_{Ext} is used for varying the voltage across R. The magnitude of the voltage across R is related to i and V_{Ext} by the following equations:

$$v_i = iR + aV_{Ext} \quad (1)$$

$$a = \frac{R}{R + R_{Ext}} \quad (2)$$

The level of LED current i changes inversely to the external control voltage V_{Ext} and the luminous intensity is varied by adjusting the LEDs current level. Since the luminous intensity of LEDs vary non-linearly with continuous DC forward current, it is difficult to adjust the luminous intensity of LEDs to the desired value by noting only the forward current in Amplitude driving technique.

In pulse width modulation driving technique, the current flowing the LEDs is periodically switched between a constant level and zero level at high frequency and the luminous intensity is controlled by adjusting the duty cycle, which is the ratio between the duration of time of application.With PWM driving technique, the average LEDs current is given by

$$T_f = DI_f \quad (3)$$

$$D = \frac{t_{on}}{T} \quad (4)$$

Due to the constant peak current level during the switching, the control of luminous intensity by dimming is independent of the forward current level. A linear relationship between the luminous flux emitted from the LEDs and the average current is obtained with the PWM driving technique. It thus eases the control of complexity of dimming.Therefore PWM driving technique provides a easier dimming function and higher colour stability compared to the amplitude driving technique. Despite the improved chromaticity and better dimming functionality, PWM driving technique has several drawbacks in practice. The usual configuration of the LEDs driver implementing PWM driving technique is the use of switched –mode power converter. However by offering better chromaticity and flexibility for dimming, the PWM driving technique is more appropriate selection.

III. DESIGN AND IMPLEMETATION

A. General Design Considerations

Due to its very low inductance value it should be designed with air core coil. Assume, coil of length l = 10mmwith N = 15 turnshas inductance of L=4.7µH.Let us find out the area(A) and radius(r) of the coil.
We know that

$$L = \frac{N^2 \mu A}{l}, \; H \quad (5)$$

also,

$$A = \frac{Ll}{H^2 \mu}, \; m^2 \quad (6)$$

Therefore, the coil area A (in sq m) becomes

$$A = \frac{L\,l}{N^2 \mu}, \; m^2 \quad (7)$$

Substituting the values of the parameters viz. L, l, N and µ, The area of the coil, A (in sq m) becomes

$$A = 0.00016622849 \; m^2$$
= 1. 666622849 sq mm

Also the radius of coil, rin meter is given by

$$r = \left(\frac{A}{\pi}\right)^{1/2}, \text{ m} \quad (8)$$

By substituting the values of the concerned parameters coil of radius becomes 14.5 mm and length 10mm with 15 turns have an inductance of 4.7µH. For 3A of current rating choose copper wire of 17 SWG[10]

B. Implementation

The fig. 1 shows the circuit diagram of a typical bilevel current driving module employing PWM technique.The LED current is regulated directly by using a current reference i_{ref} switching between two levels $I_{ref}(H)$ and $I_{ref}(L)$, through the use of an external PWM signal i_{PWM} for each loading condition corresponding to I_H and I_L.The current referencei_{ref} is a function of the PWM signal I_{PWM} and the constant dc signal I_{dc} . The current reference i_{ref} is compared with i , which is thecurrent signal of LED current detected by a 0.1 Ω sense resistor, and the error signal is used to determine the duty cycle of switch$Q$ and hence the output voltage v_f .[8] This gives rises to a linear relationship between the current reference$i_{ref}$and the LED current i_f at the corresponding level as

$$\frac{I_L}{I_H} = \frac{I_{ref(L)}}{I_{ref(H)}} \quad (9)$$

The Complete hardware setup comprising of power supply unit, control circuit, Driver circuit and buck converter is shown in fig 2. The step down transformers are used to step down the normal phase voltage (230v) to 12 V as required for the control circuit and driver circuit. The setup consists of control circuit, driver circuit and current controlled buck converter. The applied input voltage is 12V dc. The switching frequency of Switch (MOSFET) is 500 khz.Value of inductance and capacitance is 4.7µH and 44µF respectively. Results show that maximum efficacy of LED is achieved when voltage across LED is 3.6V. The output current of the converter is sensed by the current sensor circuit to generate a current signal that is compared with the externally generated reference signal to give error in the PWM controller which is then passed through the compensation network to generate control signal. The PWM modulator in the controller then compares this compensated control signal with the internally ramp signal to generate PWM control for driving power switch. Since the bilevel current driving technique is derived from the conventional PWM technique, the linearity between the average illuminance and the average current is maintained [1]

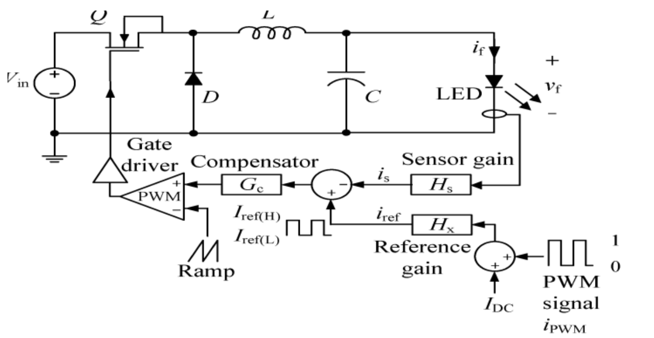

Fig.1 Prototype for implementing the bilevel current driving technique

The bilevel driving module is developed and the module is shown in fig.2.Number ofexperiments have been performed with this Laboratory set up.

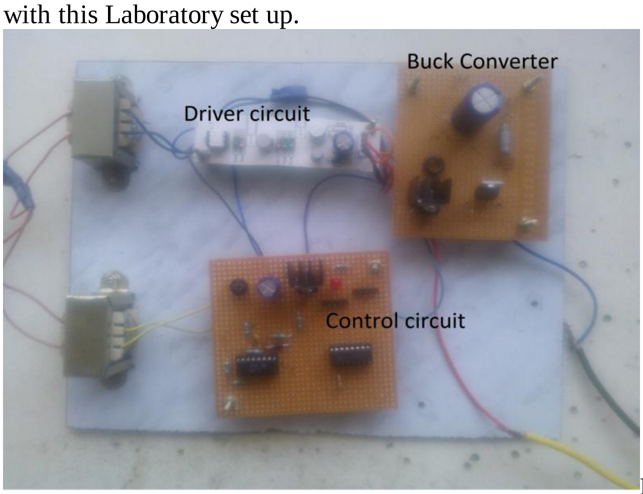

Fig. 2 Fullexperimental setup of the current-controlled buck converter

C. VIRESULTS

This experimental results and the appropriate block diagram to develop the project. The experimental setup of the proposed module is done and analyzed .This work considers the application of a current controlled buck converter to reduce the voltage by which the voltage stresses across the switch is greatly reduced and thus the high voltage gain is achieved without an extremely high duty ratio. The operation of the module is simple and it offers a competitive price in the consumer market. Thevarious experimental results obtained from the laboratory model are given in this section.

IV. EXPERIMENTALRESULTS AND DISCUSSIONS

The waveform across the LM7805 regulator, as obtained in CRO is shown in fig 3. The filtered output voltage from the capacitor is finally regulated. This voltage regulator is a device, which maintains the output voltage constant irrespective of the change in supply variations, load variations and temperature changes. Here the output voltage of the regulator is 5V under all conditions. This result tallies with the waveforms shown by Wai- Keung Lun et al [1].

Fig 3 Voltage Waveform across the Regulator (1Volt/Div)

The figs 4 and 5 show the input and output waveforms respectively of the optocoupler, MCT2E. The input waveform of the optocoupler is obtained across the pin 1 and the output waveform is obtained across the pin 5. The input of the optocoupler is 1V DC and the output obtained varies from 12V to 15V.

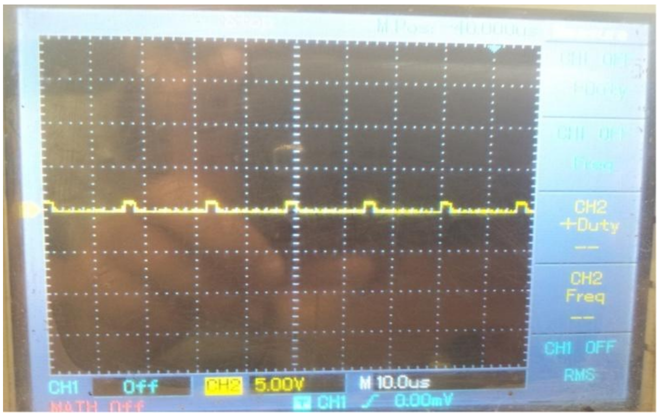

Fig 4Optocoupler input voltage waveform(1Volt/ Div)

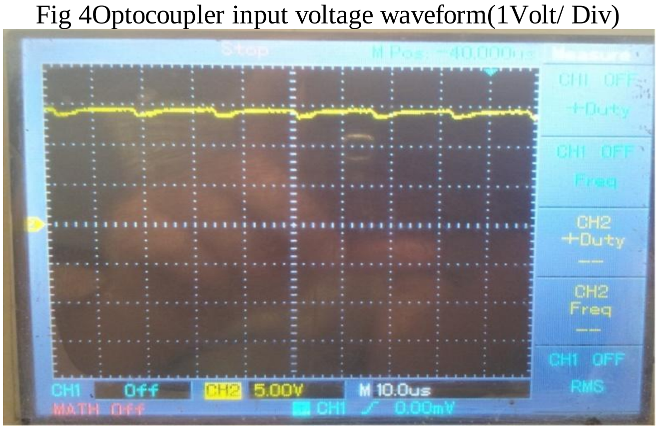

Fig 5 Output voltage waveform of Optocoupler (1Volt/ Div)

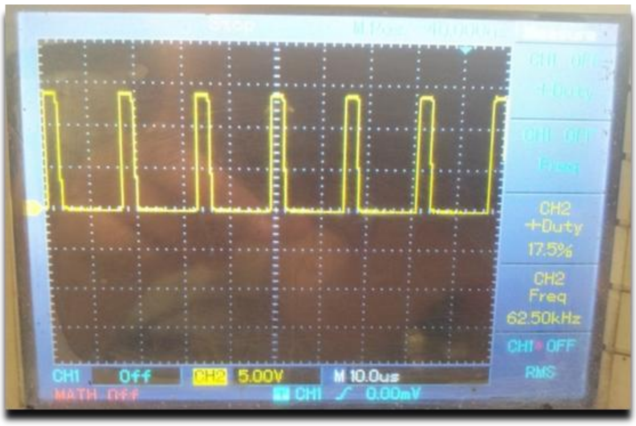

Fig 6 Output voltage waveform of the Driver circuit(1 Volt/Div)

The Fig. 6 shows the output voltage waveform of the driver circuit. The output of driver circuit is fed to the MOSFET of the buck converter to drive the MOSFET. The output of driver circuit varies from 12V to 15 V.

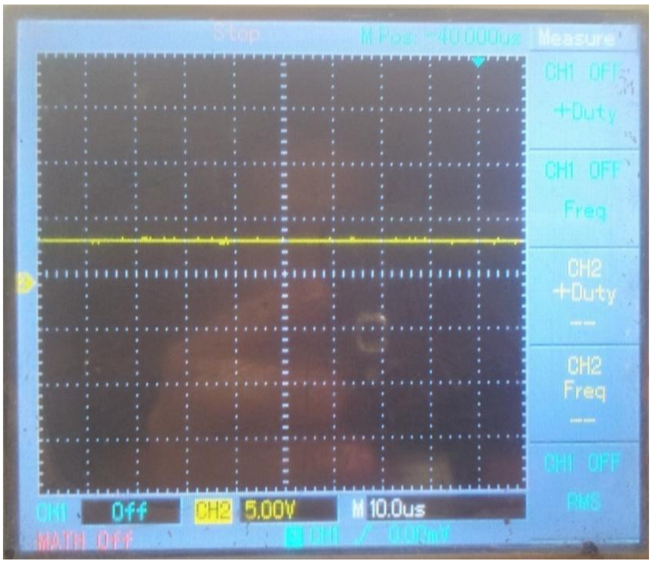

Fig 7 Output voltage waveform across LED(1Volt/Div)

The output voltage waveform across LED is shown in fig 7. The output voltage across the LED is 3.6 V. The experimental results show the output voltage is reduced..This waveform is obtained when the input voltage of 12V is given and at that time the output voltage 3.6V. The proposed module also shows better hold up time performance. Although if the output voltage is increased, the switching losses of the primary switch of the downstream dc/dc stage are still significantly lower. The brightness of the LED string powered by proposed driver circuit can be controlled by adjusting the average LED string current. The output voltage across LED string is independently regulated to the optimal value, thus leading to higher efficiency.

V. Conclusion

In the past decades, LEDs were used as small indicator light. It is now becoming an important light source in various lightning applications. Researches and engineers from different disciplines are working to improve the LEDs properties and extend their applications. To achieve these objectives, LEDs materials and their driving methods will continue to play a vital role in the development of LEDs in future. Since the optical performance of LEDs is strongly dependent on the amplitude of the applied forward current, the driving waveforms employed are critical to the overall performance of the LEDs lighting system. The influence of driving techniques on LEDs is necessary for lighting and power electronics designers. The differences in the luminous intensity and efficacy between the amplitude mode and Pulse width modulation –driven LEDs are analyzed.The advantages and disadvantages of these driving techniques are discussed.

The bilevelcurrent driving technique is proposed as driving solution that hybridizes the advantages of amplitude mode and pulse width modulation techniques. Since LEDs exhibit better luminous efficacy at low forward current, the luminous efficacy of LEDs can be improved by introducing a DC- offset into the conventional pulse width modulation driving current. In utilizing the bilevel current driving technique, the dimming flexibility of LEDs is retained by using duty cycles as control parameter for adjusting luminous intensity. The implementation details of the bilevel current driving technique are discussed. This driving technique can be implemented easily on conventional switching mode converters. In this work bilevel current driving technique was implemented using current controlled buck converter.

A fast dynamic response is required for LEDs driver based on Pulse width modulation dimming. A similar requirement is applicable to the LEDs driver based on the proposed bilevel driving technique. The methods for improving the converter's dynamic response and minimizing the output current's ripples are desired, especially in colour–sensitive lighting techniques.

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