논문 17-42-08-17 The Journal of Korean Institute of Communications and Information Sciences '17-08 Vol.42 No.08
https://doi.org/10.7840/kics.2017.42.8.1621

LED 램프를 위한 지능형 범용 드라이버 회로 설계

Design of An Intelligent Universal Driver Circuit for LED Lights

Md. Tanvir Hossan[◆], Amirul Islam[*], Yeong Min Jang[°]

ABSTRACT

This paper presents a universal driver circuit for light emitting diode (LED) using linear current regulation technology. The proposed driver circuit has a unique feature (i.e., universality) which operates in both alternating current (AC) or direct current (DC) domain of the supply. Additional features, such as improved power factor, lower self-power consumption, lower cost, design simplicity for higher load makes it distinctive than existing LED driver circuits in the market. To verify the feasibility of the proposed driver circuit, a laboratory prototype has been designed and checked from lighter load (3 watt) to the higher load (30 watt).

Key Words : Universal driver circuit (UDC), LED driver, DPDT, SPDT, constant load current

Ⅰ. Introduction

Light emitting diode (LED) has attracted attention in next generation industry due to the revolution of the lighting industry and its versatile use in both indoor and outdoor illuminations. This revolution starts from tungsten bulb to incandescent bulb, later compact fluorescent lamp (CFL) and finally LED lights. The efficiency of LED light is around 30% whereas conventional CFL and the incandescent bulb has 8% and 2% respectively[1]. Additionally, LED light has many advanced features such as less mercury radiation, production of less heat, higher light projection in solicited way, and improvised to shock, vibration or quick environment changes. It is compact, long life, and easy to install on printed circuit board (PCB) which makes it more friendly lighting source[2]. Moreover, application of LED light is no more confined to indoor and outdoor lighting purpose. Recently, a demand of LED is growing rapidly in wireless communication as a transmitter due to its fast switching time that human eye cannot detect[3,4]. It is used in vehicle-to-vehicle communication[5], smart digital signage system, indoor positioning system[6].

LEDs can be connected in parallel and/or series as load, is driven by either constant voltage or constant current. Constant voltage LED driver and constant current LED driver are used for low power LED and high power LED respectively. The lumen of LED is directly proportional to the current. The overall efficiency of LEDs can be affected by adjusting its brightness[7]. However, the operating current can control the brightness of the LEDs. Therefore, in constant voltage LED driver system, an excess forward current would result in an extra heat for LED, which can reduce its lifespan. So, constant current LED driver is most promising over constant voltage driver.

On the other hand, it is required to choose the

※ This research work was supported by Institute for Information & communications Technology Promotion (IITP) grant funded by the Korea government (MSIP).
◆ First Author : Department of Electronics Engineering, Kookmin University, tanvir.hossan.shaon@gmail.com, 학생회원
° Corresponding Author : Department of Electronics Engineering, Kookmin University, yjang@kookmin.ac.kr, 종신회원
* Department of Electronics Engineering, Kookmin University, amirul.0903118@gmail.com
논문번호 : KICS2017-05-160, Received May 30, 2017; Revised August 14, 2017; Accepted Revised August 14, 2017

effective component and efficient technology to make the driver circuit more cost effective, simple, compact, reliable and convenient. There are several driver circuits is available in the market. It is a common practice to use a high-value inductor in most of the driver circuits in order to reduce the ripple current through the LEDs successfully[8]. Generally, inductor consumes much energy because of high inductive resistance. This energy can be dissipated as heat or developed as voltage or current stress to the connected devices. Henceforth, efficiency of the driver is affected by inductor[9].

Pulse-width modulation (PWM) is one of the favorite techniques for LEDs in switched-mode driver circuits. Traditional non-isolated step-down PWM buck converters may suffer from reduced efficiency due to the long diode freewheeling time at small duty cycles[10]. The major drawback of PWM based drive circuit is that if all LED strings are turned on or off simultaneously, the input–output power periodically undergoes abrupt changes, causing massive pulsating input/output current, decreased operating efficiency and increased power bus ripple[11]. There is some non-isolated converter used as power factor pre-regulator, such as buck-boost converters, single-ended primary inductor, CUK and flyback converters[12]. Usually, these converters are suitable for small power applications[1].

Conventionally, LED is driven by direct current (DC) power supply. For alternating current (AC) power supply, the LED driver either use a step-down transformer or a bridge rectifier. Although there is available some AC utility source driving LED (e.g., AC-LED) that has some disadvantages notably conduction angle causes harmonic distortion and low power factor [13]. There is no other available driver circuit which is operational in both DC and AC power supply. Therefore, it is required to choose different driver circuit for individual power domain.

This paper proposes a novel architecture of a driver circuit for LED light which is operated in a wide range of power supply by both AC (180V to 240V) and DC (12V to 15V) power domain using linear current regulation technology. The proposed driver circuit is not only universal in different power domain but also efficient in the technical and commercial point of view. The rest of the paper is organized as follows. Section II presents the I-V characteristics of LED using Taylor series expression. Whereas section III of the paper represents the overall requirements for the proposed architecture where we point out the design considerations for the LED drivers circuit in a flow diagram. A brief description of practical implementation for proposed system is represented in section IV. Before concluding this paper in section VI, an evaluation of driver performance has discussed in section V.

Ⅱ. I-V Characteristic of LED using Taylor Series

Taylor series explains the nonlinear I–V characteristics of LEDs [14]. Moreover, current and conductance of both AC and DC domain is calculating from the same series (1):

$$i_{LED} = I_{Sat}\left(e^{\frac{q \cdot v_{LED}}{k.T}} - 1\right) \tag{1}$$

Where v_{LED} is LED terminal voltage, i_{LED} LED forward current through LED, I_{Sat} is saturation current of LEDs, q is the magnitude of electron charge (i.e., 1.602×10^{-19}), k is Boltzmann's constant (i.e., 1.38×10^{-23}), T is absolute temperature (i.e., $273+T_a$). Fig. 1(a). shows, a DC current source I_{LED} and a low frequency current source, i_{LED} connected to a LED. Therefore, (1) can be expressed regarding DC and AC components, as shown in (2).

$$I_{LED} + i_{LED} = I_{Sat}\left(e^{\frac{V_{LED}+v_{LED}}{V_T}}\right) \tag{2}$$

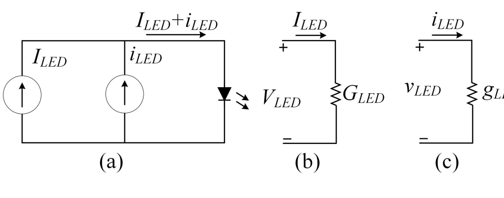

Fig. 1. (a) A DC current source and a low frequency current source with LED, (b) DC, and (c) low frequency equivalent circuits.

Where $V_T = \frac{k.T}{q}$. Therefore, the Taylor series can be expressed as follows (3):

$$I_{LED} + i_{LED} = I_{Sat}\left(\sum_{n=1}^{\infty} \frac{\left(\frac{V_{LED}}{V_T}\right)^n}{n!}\right)\left(1 + \frac{v_{LED}}{V_T} + \frac{(v_{LED})^2}{2}.V_T^2\right) \tag{3}$$

To minimize the complexity from the above equation by neglecting the term $(v_{LED})^2$from it, we can write the equation as the DC and low frequency components which is shown in (4)

$$I_{LED} + i_{LED} = I_{Sat}\left(\sum_{n=1}^{\infty} \frac{\left(\frac{V_{LED}}{V_T}\right)^n}{n!}\right) + \frac{I_{Sat} * v_{LED}}{V_T}\left(\sum_{n=1}^{\infty} \frac{\left(\frac{V_{LED}}{V_T}\right)^n}{n!}\right) \tag{4}$$

The equivalent DC conductance G_{LED} of the Fig. 1(b), can be calculated in (5):

$$G_{LED} = \frac{I_{LED}}{V_{LED}} = \frac{I_{Sat}}{V_{LED}}\left(\sum_{n=1}^{5} \frac{\left(\frac{q.V_{LED}}{k(273+T_a)}\right)^n}{n!}\right) \tag{5}$$

Where T_a is the ambient temperature. The equivalent small-signal conductance, g_{LED} of the low frequency equivalent circuit in Fig. 1(c). can be calculated from following (6):

$$g_{LED} = \frac{i_{LED}}{v_{LED}} = \frac{q.I_{Sat}}{k(273+T_a)}\left(\sum_{n=1}^{5} \frac{\left(\frac{q.V_{LED}}{k(273+T_a)}\right)^n}{n!}\right) \tag{6}$$

Ⅲ. Proposed Model

Our proposed universal driver circuit (UDC) is consist of two different relays. One of the relays is double-pole-double-through (DPDT) relay which is driven by AC supply. This DPDT relay is denoted as relay 1 in Fig. 4. Relay 2 is a single-pole-double-through (SPDT) relay and it is driven by DC power supply. These two relay is embedded in UDC. If the UDC connects with the AC power supply, then the relay 1 is tripped, allows a rectified and regulated DC voltage to the load. Whereas, relay 2 is tripped for DC power supply. Fig. 2 and 3 shows the flow chart and block diagram of our proposed model respectively.

The voltage range for AC and DC supply for UDC is shown in table 1.

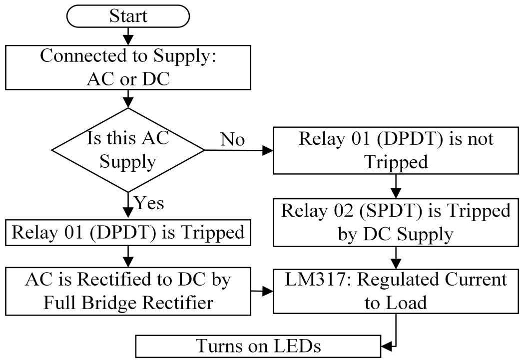

Fig. 2. Flow diagram of proposed UDC for LED light

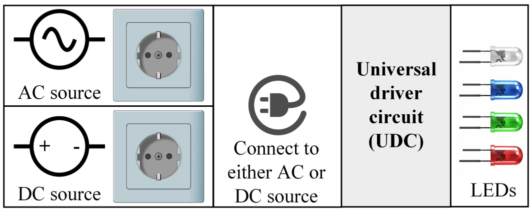

Fig. 3. Block diagram of UDC

Table 1. Power supply specification for UDC

Specification	Values
AC supply	
Input voltage	180V~240V
Input line frequency	50Hz
DC supply	
Input voltage	12V~15V

Ⅳ. Practical Implementation

4.1 Working methodology of UDC

A UDC can be defined as a driver circuit which is adjustable to or appropriates for all requirement of any power supply and not restricted to a single source. To make the driver circuit universal, we are proposed to isolate one power supply (either AC or DC) for a certain path of the UDC and at the same time allows to pass through another path of it. There are different rows of change over terminals in a relay and each row has several terminals. There is a control coil in a row which surrounds an iron core. When the power supply pass through the control coil, it generates a electromagnetic force. This forces cause an impact to trip relay. In another row, the'COM' (Common) terminally connects with the 'NC' (Normally Closed) terminal. There is another terminal named the 'NO' (Normally Open) in each row. In Fig. 4. there are two change over terminal in relay 1. Power path 1 connects with one row of relay 1. On the other hand, power path 2 connects with another row of the same relay. The construction of SPDT has similarity with the DPDT relay. But the difference is it has one row instead of two. The relay 1 has only tripped when the driver circuit is connected to the AC power supply and remained ineffective when it is connected with the DC power supply.

Isolate AC power at power path 1: In Fig. 4. rated AC power energizes control coil of relay 1 and 'COM' terminal starts to be attracted with 'NO' terminal. Power path 1 is connected between the 'COM' and 'NC' terminal of this row. Therefore, the probability of passing AC power through the power path 1 is near to zero. The switching time for relay 1 is lying between 5ms to 15ms which cause a high transient voltage spike for a very short period of time (between 1ms to 1μs). This voltage spike can strike to the power path 1. A combination of an inductor, a switching transistor (BC548) and the SPDT relay are used in the power path 1 to mitigate the chance of passing voltage spike through it. The general expression of an inductor is $X_L = 2\pi f L$, where f is the frequency in Hertz and L is the inductance in Henries. Reactance will increase if frequency or inductance increase. Here, inductance shows impedance in AC power supply and short in DC power supply. Concurrently, if there is a chance of any remaining voltage spike after the inductor, then it can easily abate the by the relay 2 (SPDT relay). A small and certain rated voltage of DC power supply, the relay 1 operates. A diode is connected to the SPDT relay to protect the switching transistor from the instantaneous current of the relay coil, and the task is done the diode by providing a path for that current when the coil is switched off.

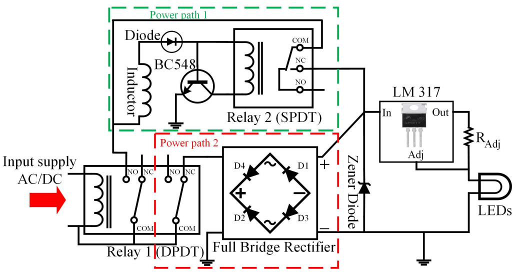

Fig. 4. Circuit block representation of UDC

Additionally, power path 2 is connected between the 'COM' and 'NO' terminal of the other row of relay 1. Therefore, AC power can easily pass through the power path 2. The full bridge rectifier serves to convert single phase AC input into a DC output; supplies an output of pulsed DC. A capacitor, known as a reservoir (or smoothing) capacitor is added to lessen the variation in the rectified AC output voltage waveform from the bridge. This ripple free pure DC is then deployed to the load.

Isolate DC power at power path 2: The chosen range of DC power supply is not enough to energize the control coil of relay 1 compare with AC. Therefore, DC can pass through path 1 but cannot pass through 2. The transistor BC548 is only switching when supply current is above the base current of this transistor. When the transistor is switching, it allows DC power to apply across the relay 2. DC power energize control coil of relay 2 and 'COM' terminal starts to be attracted with 'NO' terminal. Later, DC power is applied to the load because the load also connects with 'NO' terminal of the relay 2.

4.2 Delivering constant current to the load

We are using a 3-terminal positive voltage regulator (LM317) which can deliver a constant current to the load (LED light). By connecting a fixed resistor between the adjustable and output pins (R_{Adj}), the LM317 can deliver a desire fixed current more than 1.5A. This constant current is calculating by the following equation:

$$I = \frac{V_{ref}}{R_{Adj}} \tag{7}$$

In (7), V_{ref} is the voltage difference between 'OUT' pin and 'ADJ' pin. If the voltage across the LM317 IC has changed rapidly, the current regulator cannot deliver constant current to the LED light. Therefore, a reversely connect zener diode can deliver a constant voltage to LM317. The zener diode protects the regulator from the ripple of the supply voltage or the load current variation till its current drops below the reverse breakdown region. The list of component for the driver circuit is listed in the table 2.

PCB layout of our proposed UDC for LED light are shown in Figure 5.

Table 2. Basic circuit parameter

Component	Value
White LED	3.2V, 300mA, 1W
Diode (D1-D5)	600V/0.5A
Zener Diode (1N4744A)	15V
Reservoir Cap	330μF/400V
Inductor	150mH
Transistor (BC548)	V_{EBO}: 5V; IC : 100mA
Current Regulator (LM317)	V_0: 1.2~37V, I_0>1.5A
Relay 1 (DPDT)	$V_{in}\le$240V; $I_{in}\le$ 10A
Relay 2 (SPDT)	$V_{in}\le$ 12~28V; $I_{in}\le$15A

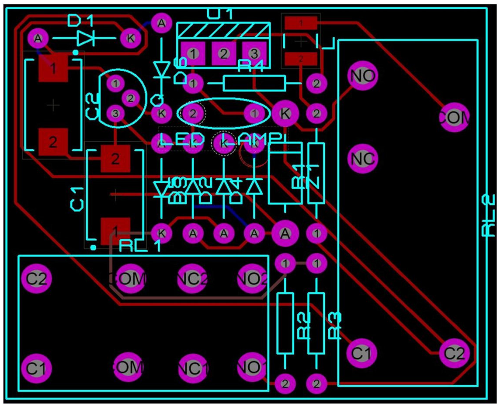

Fig. 5. PCB layout of UDC

V. Result and discussion

5.1 Performance analysis

From Table 3, input current (I_{in}) is increased with the increasing demand of load current (I_L), but load voltage (V_L) is not varying throughout the whole performance. R_{in} is the resistor connected in series with the full bridge rectifier. The chosen value of zener diode voltage (V_Z) is fixed throughout the whole operation and a resistor R_Z is connected before zener diode which is also varying with the load. Power factor is decreased with the increase of load, but it is still near to the unity (up to 30W load).

Fig. 5. shows that drive deliver constant current to the lighter load from a wide range of input AC

Table 3. Performance evaluation for UDC

Load (W)	R_{in} (Ω)	R_z(Ω)	C_1	I_{in} (A)	V_z (V)	V_L (V)	I_z (A)	p.f.
3	470	220	100/400	0.35	15	9.6	0.3	0.998
6	240	100	100/400	0.7	15	9.6	0.6	0.998
9	150	68	330/400	1.1	15	9.6	0.9	0.998
12	130	56	330/400	1.3	15	9.6	1.2	0.996
15	100	47	330/400	1.6	15	9.6	1.5	0.995
18	91	36	330/400	1.9	15	9.6	1.8	0.993
21	75	33	430/400	2.2	15	9.6	2.1	0.993
24	68	27	430/400	2.5	15	9.6	2.4	0.993
27	62	22	430/400	2.8	15	9.6	2.7	0.993
30	51	24	430/400	3.15	15	9.6	3.0	0.991

(180-240V) or DC (12-15V) voltage and the performance is little fluctuated for a higher load. Performance of the driver is almost similar to the load after 210V AC supply.

Table 4 shows that the load has adjusted by adjusting R_{Adj} value. Single LM317 can drive up-to 15 LEDs for both (AC and DC) power supply. Hence, we are connecting two parallel LM317 to handle 30 LED lights.

Table 4. Data for single LM317 (3W to 15W load)

V_{in} (V)	Load (LED)	R_{Adj} (Ω)	V_{Adj} (V)	V_{load} (V)	I_{load} (A)
15	3W	3.9	1.2	9.6	0.3
15	6W	2.0	1.2	9.6	0.6
15	9W	1.3	1.2	9.6	0.9
15	12W	1.0	1.2	9.6	1.2
15	15W	0.82	1.2	9.6	1.5

5.2 Cost analysis

There are different driver circuit has found in the market which is costly and works only in one domain of the power supply[15]. On the contrary, the components we are used in the driver circuit is available to everywhere and not costly either. The overall cost has been calculated for our proposed driver is around $1.5 along with the price of 30 LEDs (1W, 300mA). Table 5 shows, a price comparison between available driver circuit in the market and our proposed driver circuit.

Table 5. Cost comparison of available driver with UDC

Driver specification	Price
Available driver circuit	
12V DC, 30W	$15.5
12V DC, 36W, 700mA (constant voltage output)	$14
85~264Vac, 50W, 900~1000mA	$14
120Vac, 12W, 700mA	$9
Proposed UDC	
12~15V DC or 180~240V AC, 30W, 300mA, (constant current output)	$1.5

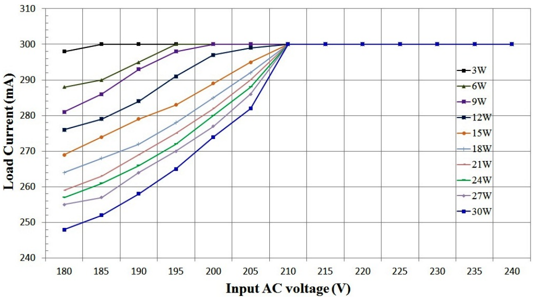

Fig. 6. Input AC voltage versus load current for 3W to 30W load

Ⅵ. Conclusions

A low-cost UDC for high power LED light is proposed, designed, and constructed. We made 10 different load (3~30W) to evaluate performance. For all type of load, the driver circuit shows almost equivalent performance in both AC and DC power supply. The number of the capacitive component is more over inductive component, keeps the power factor leading at AC domain. Self- power consumption of proposed driver is 4%, which makes it superior to a typical driver circuit. Moreover, the unique feature of this driver is universality that gives the consumer a choice to connect any type of power supply (either AC or DC) without any trouble.

References

[1] Z. Ye, F. Greenfeld, and Z. Liang, "Design considerations of a high power factor SEPIC converter for high brightness white LED lighting applications," in *Proc. 2008 IEEE Power Electron. Specialists Conf.*, pp. 2657-2663, Rhodes, 2008.

[2] C. Y. Wu, T. F. Wu, J. R. Tsai, Y. M. Chen, and C. C. Chen, "Multistring LED backlight driving system for LCD panels with color sequential display and area control," *IEEE Trans. Ind. Electron.*, vol. 55, no. 10, pp. 3791-3800, Oct. 2008.

[3] T. Nguyen, A. Islam, T. Hossan, and Y. M. Jang, "Current status and performance analysis of optical camera communication technologies

for 5G networks," *IEEE Access*, vol. 5, no. 1, pp. 4574-4594, Mar. 2017.

[4] R. K. Mondal, N. Saha, and Y. M. Jang, "Performance analysis of spatial multiplexing in MIMO based visible light communication system," *J. KICS,* vol. 38C, no. 9, pp. 797-801, Sept. 2013.

[5] T. Nguyen, A. Islam, and Y. M. Jang, "Region-of-interest signaling vehicular system using optical camera communications," *IEEE Photonics J.*, vol. 9, no. 1, pp. 1-20, Feb. 2017.

[6] M. T. Hossan, M. Z. Chowdhury, A. Islam, and Y. M. Jang, "Simplified photogrammetry using optical camera communication for indoor positioning," in *Proc. 2017 ICUFN*, pp. 126-130, Milan, Italy, Jul. 2017.

[7] *Maxim Integrated website* (2017), from http://www.maximic.com.

[8] J. A. Villarejo, J. Sebastian, F. Soto, and E. de Jodar, "Optimizing the design of single-stage power-factor correctors," *IEEE Trans. Ind. Electron.*, vol. 54, no. 3, pp. 1472-1482, Jun. 2007.

[9] X. Qu, S. C. Wong, and C. K. Tse, "Resonance-assisted buck converter for offline driving of power LED replacement lamps," *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 532-540, Feb. 2011.

[10] C. Zhao, X. Xie, and S. Liu, "A simple precise capacitive current balancing method for the multi-output LED drivers," in *Proc. 2012 IEEE ECCE*, pp. 3257-3263, Raleigh, NC, Nov. 2012.

[11] M. Doshi and R. Zane, "Digital architecture for driving large LED arrays with dynamic bus voltage regulation and phase shifted PWM," in *Proc. APEC 07 - 22nd Annual IEEE Applied Power Electron. Conf. and Exposition*, pp. 287-293, Anaheim, CA, USA, 2007.

[12] I. Abbasi and N. Z. Yahaya, "Development of universal LED driver for low power application," in *Proc. 2014 8th Asia Modelling Symp.*, pp. 229-234, Taipei, 2014.

[13] M. Miskin and J. N. Anderson, *AC light emitting diode and AC LED drive methods and apparatus*, U.S. patent 7489086 B2, Feb. 2009.

[14] R.-L. Lin, C.-C. Lee, and Y.-C. Chang, "Optimal design of LED array for single-loop CCM buck-boost LED driver," *2011 IEEE Ind. Appl. Soc. Annu. Meeting*, pp. 1-5, Orlando, FL, 2011.

[15] amazon website (2017). from https://www.amazon.com

Md. Tanvir Hossan

2009년~2013년 : B.Sc. in Electrical & Electronic Engineering, Khulna University of Engineering & Technology, Bangladesh. 2016년~: M.Sc. in Electronics Engineering, Kookmin University, Korea (continue).

Research Interest : optical wireless communication, optical camera communication, autonomous vehicle, artificial intelligence, 5G mobile communication, internet of thing, and circuit design.

Amirul Islam

2010년~2014년 : B.Sc. in Electrical & Electronic Engineering, Khulna University of Engineering & Technology, Bangladesh. 2015년~2017년 : M.Sc. in Electronics Engineering, Kookmin University, Korea.

Research Interest : optical camera communication, location-based services, automotive optical vehicular communication, 5G networking, and artificial intelligence.

Yeong Min Jang

1985년 : 경북대학교 전자공학과 학사

1987년 : 경북대학교 전자공학과 석사

1999년 : University of Massachusetts 컴퓨터학부 박사

Research Interest : 6G mobile communications, optical wireless communications, optical camera communication, multiscreen convergence, public safety, and Internet of Things (IoT).