Analysis of the factors affecting operation and efficiency of power LED drivers and circuit design

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Although LEDs (Light Emitting Diodes) were discovered in 1900s, they have been semiconductor materials widely used in lighting industry due to its structure developed in recent years. LEDs are preferred for their advantages such as energy saving, long life, durability, usability for both indoor and outdoor applications. Optimum conditions should be provided for LED in order to benefit from LED lighting in a sufficient manner. Therefore, in this study, we numerically and experimentally focused the factors affecting operation and efficiency of LED drivers such as driving current, drooping and auger effects, luminance efficiency and LED temperature. These factors have crucial importance on operation efficiency of LED driver circuits. Also, we experimentally designed three different current limited buck type Power LED driver circuits; (i) using a balast resistor, (ii) LM317 regulator, (iii) switching regulator by MC34063A.

1. Introduction

Due to their many advantages, LEDs have taken their places in lighting systems in recent years. Efficiency values for LEDs are higher than other conventional lighting equipment. Their lifetimes can be up to 50.000-100.000 hours under correct conditions [1]. In order to make full advantage of LEDs, their driving circuits should be designed correctly, and driving current should be set correctly. Detection of the point where LED is saturated is very important. Under improper conditions, light spectrum of LEDs may shift, power may drop, and lifetime may shorten. Heat is among the factors that affect driver efficiency [2]. LED drivers may be current limiting or voltage limiting. Current limiting is more proper for LED structure, because this way the needed number of LEDs can be driven without changing the driver design. There are two types of LED drivers; linear regulator and switching regulator. These can be buck, boost, or buck-boost type drivers according to intended use. Buck type driver circuits are used when output voltage is lower than input voltage, and their efficiency values are high. Boost type drivers are preferred when output voltage is higher than input voltage. Buck-boost type driver circuits are used when output voltage can be higher or lower than input voltage, and their efficiency is lower [3]. There are some similar studies about LED driver circuit design in literature [4-9]. However, unlike the other studies, in this study, we numerically and experimentally investigated the factors affecting operation and efficiency of LED drivers; (i) to determine proper driving current, (ii) to determine the ratio of drooping and auger effects, (iii) changes in LED circuit electrical efficiency with heat, (iv)

optimization of lighting efficiency of LED driver circuit as detailed.

2. Driver circuit design

2.1 Current limiting resistor driver circuit design

In the proposed study, current limiting LED driver circuits were designed using resistance only. In order to limit the current in this driver circuit, 1W Cree brand 90lm/W efficient power LEDs were connected with a serial resistor in Fig.1. First, LED saturation current was detected. For this, currents ranging from 5mA to 350mA were applied on the LED.
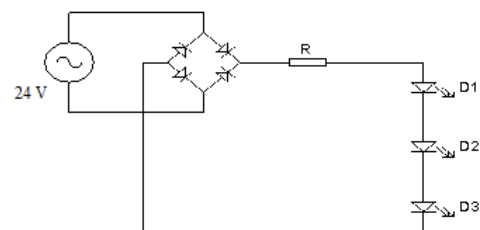

Fig. 1. Power LED driver circuit design using a balast resistor

Calculation of parameters of current be constant:

$$P_{out} = I_o \times V_f \qquad (1)$$

$$R = (V_p - V_f) \: / \: I_o \qquad (2)$$

$$P_R = I_o \times V_R \qquad (3)$$

$$P_{total} = P_{out} + P_R \qquad (4)$$

$$\eta = P_{out} / P_{total} \qquad (5)$$

where P_{out} is output power , I_o is drive current, V_f is the power LED threshold voltage value, V_p is input voltage, P_R is power consumed in the resistor, η is circuit efficiency.

In order to calculate the proper driving current, 24V voltage was applied to circuit admittance. Table 1 shows total lumen values for three LEDs. According to obtained data, maximum luminance value was calculated as 260 lm in 320mA driving current.

Table 1. LED Current and calculated illuminations values

V_{in}	R	I_{LED}	$Ø_{LED}$
V	Ω	mA	lm
24	2808	5	6
24	1404	10	11
24	280	50	56
24	200	70	78
24	156	90	101
24	117	120	135
24	100	140	157
24	87	160	178
24	70	200	205
24	63	220	230
24	56	250	243
24	50	280	257
24	46	300	260
24	43	320	260
24	42	330	260
24	40	350	260
24	39	360	260

According to the obtained data, as LED driving current value increases, lumen from LED doesn't increase linearly. As can be seen from the Fig.2. even the current passing on LED increases, LED luminescence doesn't increase linearly [10]. On the other hand, "droop" amount increases as LED driving current increases. Research conducted at California Santa Barbara University between 2007-2011 revealed that "droop" couldn't be eliminated but minimized [11]. The reason for drooping is the Auger Recombination. Auger Recombination; refers to the emission of an electron, as a result of the transition of an electron in the inner shell of another electron. The space left by an electron ejected from the atomic nucleus energy level can be filled by another electron of higher energy. Energy is yielded during this transition process. This energy is generally emitted from the atom as a photon, but this is not always the case. Energy is transferred to another electron in the atom, and ejects it from atom by ripping it. This secondary electron emitted is called Auger Electron.

Kinetic energy of Auger electron leaving the atom equals to the difference between first electronic transition energy and Auger electron ionization energy [12].
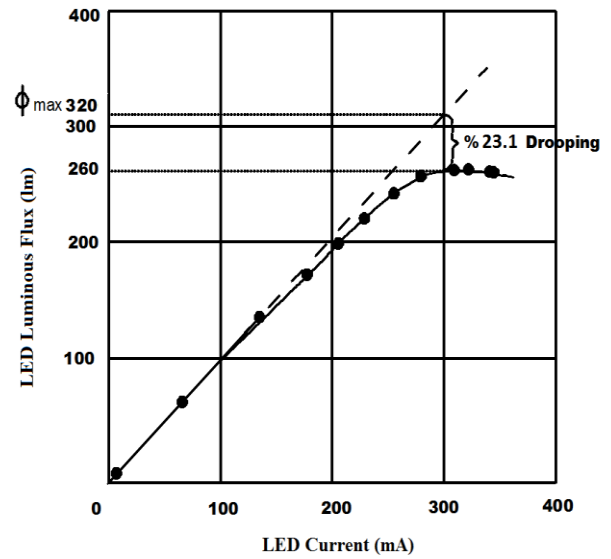

Fig. 2. LED driving current and LED luminous flux change.

Drooping in LEDs results from Auger recombination. As photon is emitted in LED, a space is formed. Energy is yielded during the transition. Sometimes this energy is not emitted as photon, and transferred to another electron. Therefore, LED doesn't photon and lumen value decreases. As LEDs were driven with 320mA, their input voltage was lowered, and total power of the circuit was calculated. Circuit input voltage total power change is presented in Fig. 3 (a), and circuit input voltage electrical efficiency change is experimentally presented in Fig. 3 (b).

(a)

(b)
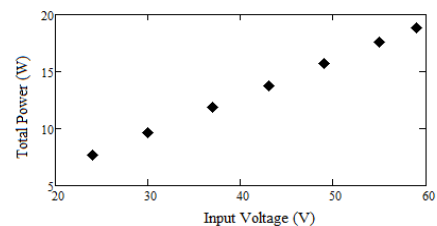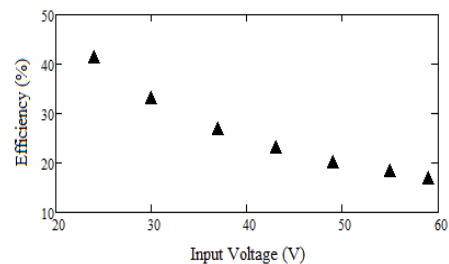
Fig. 3. Experimantal results of the variation of circuit total powerand efficiency with the input voltage

As can be seen in Fig. 4, as input voltage increases, voltage values decrease, because the power spent on the resistor increases. Because energy on the resistance in driver circuit was given off as heat, the circuit had an over-heating problem. Due to heating, circuit current changed as well, this may be damaging for LED structure and circuit efficiency. The greatest advantage of driver circuit with a resistor is the cost, and the most important disadvantage is low efficiency, and high heating. LED heat change is another important factor for the efficiency of LEDs. Table 2 presents the current values passing on the LED and circuit efficiency values, when LEDs in the circuit are heated. Fig. 4 presents changes in the LED heat and circuit efficiency values. Efficiency values were changed approximately 0.09% by LED temperature changes from 25^0C to 75^0C.

Table 2. The variation of LED current-voltage values with the LED temperature under the constant input voltage.

| V_{in}	R	T	I_{LED}	V_{LED1}	P_{out}	P_R	P_{total}	Efficiency (η)
V	Ω	^{0}C	mA	V	W	W	W	%
24	44	25	320	3.90	3.74	14.08	17.82	21.0
24	44	30	321	3.88	3.74	14.12	17.86	20.9
24	44	35	322	3.87	3.74	14.17	17.90	20.9
24	44	40	324	3.85	3.74	14.26	18.00	20.8
24	44	45	325	3.83	3.74	14.30	18.04	20.7
24	44	50	327	3.82	3.74	14.39	18.13	20.6
24	44	55	328	3.81	3.75	14.43	18.18	20.6
24	44	60	329	3.79	3.74	14.48	18.22	20.5
24	44	65	331	3.78	3.76	14.56	18.32	20.5
24	44	70	332	3.73	3.72	14.61	18.33	20.3
24	44	75	334	3.70	3.71	14.70	18.40	20.1
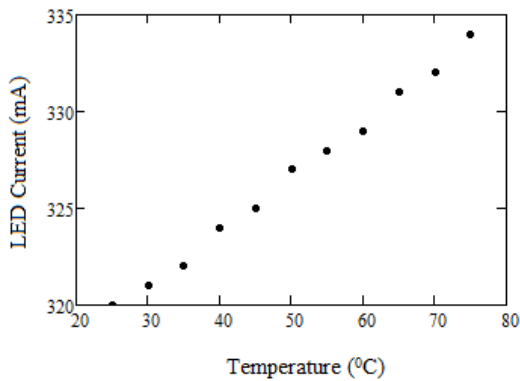
Fig. 4. Changes in LED heat and driver circuit efficiency.

2.2 Driver Circuit Design with Linear Regulator

In this part of the research, a driver circuit was designed with a linear regulator. On circuit admittance, 220 volts line voltage was applied, and the directed voltage was passed on linear regulator. In this circuit, 3 1W Cree 90lm/W power LEDs were used. In driver circuit design, LM317 convertor was used. The LM317 and driver circuit design can be seen in Fig. 5 and Fig. 6 respectively. Working principle of the convertor is creating 1.25 V on R1 resistance between output and adjust points [13].
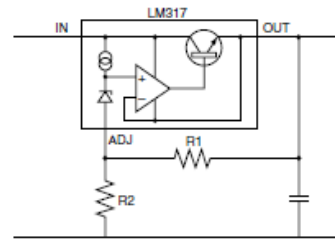

Fig. 5. The LM317 regulator

$$V_{out} = 1.25 \times \frac{1 + R_2}{R_1} \qquad (6)$$

$$I_{limit} = \frac{1.2}{R1} \qquad (7)$$

$$P_{out} = U_{out} \times I_{limit} \qquad (8)$$

$$\eta = \frac{Pout}{Ptotal} \qquad (9)$$

where V_{out} is circuit output voltage, I_{limit} is drive current value, Pout is output power, η is circuit efficiency. In this LED driver circuit design, input voltage was 24V and the current was limited at 320 mA. In Fig. 7. (a) shows LED driver circuit input voltage, and changes in total power spent in the circuit and Fig. 7.(b) presents driver circuit input voltage and changes in circuit efficiency values.
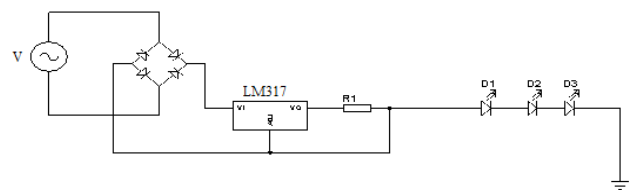

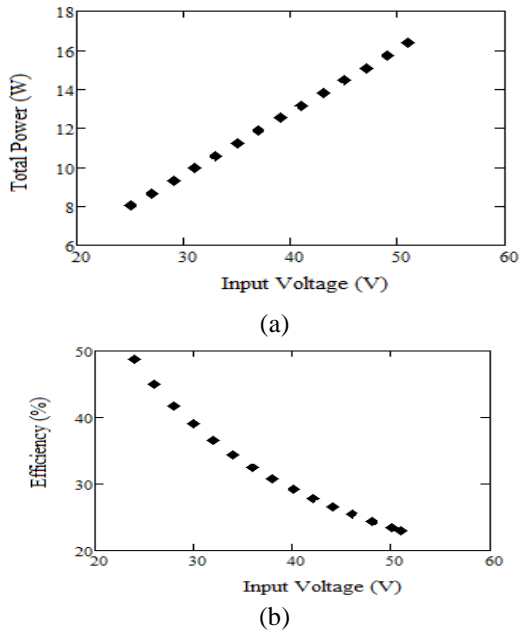*Fig. 6. Driver circuit design using linear regulator*

(a)

(b)

Fig. 7. Experimantal results of the variation of (a) the total power with the input voltage (b)the circuit output efficiency against input voltage

Output power circuit losses were calculated and according to the analyses circuit efficiency values for 24V, 30V, 40V, and 50V input voltages respectively were %48.75, %39.00, %29.25, %23.40. As input voltage of the circuit was increased, efficiency decreased, and the circuit overheated. Fig. 8 shows the changes in LED heat and circuit efficiency values.
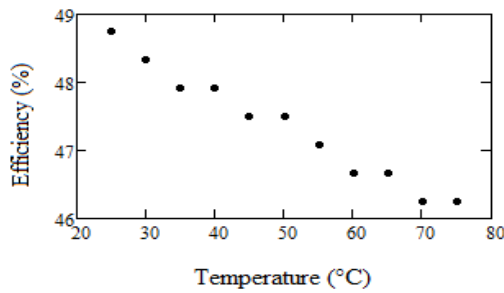

Fig. 8. The variation of the circuit output efficiency against the LED temperature

2.3 Designing driver circuit with switching regulator

In this study, a switching driver circuit was designed. For the switching driver circuit design, MC34063 regulator (regulator efficiency 96%) was used. The switching regulator and driver circuit design can be seen in Fig.9. and Fig.10 respectively.
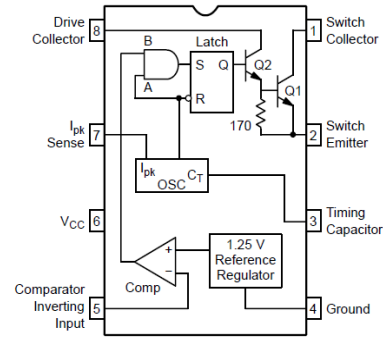

Fig. 9. The MC34063 switching regulator

Driving circuit was conducted on 3 1W Cree brand power LEDs with 90lm/W efficiency. The important point here is the calculation of circuit element values to maximize the output lighting efficiency. Element values were calculated according to regulator data sheet and LED structure [14].
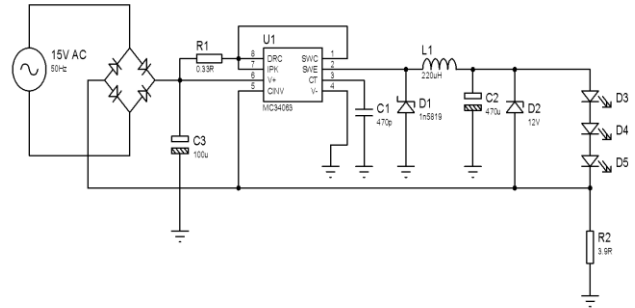

Fig. 10. Designed Circuit model using switching regulator MC34063A

The circuit power loss relationships are given in the following;

Conduction Loss in Power Switch;

$$P_{swicth,\,cond} = I_L \text{ x } V_{SAT} \text{ x Duty cycle} \qquad (10)$$

Conduction Loss in Sensing Resistor;

$$P_{sensing,\,res} = (I_{Lavg} \text{ x } \frac{t_{on}}{t_{off}})^{\,2} \text{ x } R_{sc} \text{ x } 0{,}001 \qquad (11)$$

Conduction Loss in Diode;

$$P_{diode,\,cond} = (V_F \text{ x } I_{out}) \text{ x } (1\text{- duty cycle}) \qquad (12)$$

Inductor Winding Losses;

$$P_{ind,\,winding} = (I_{out})^2 \text{ x } R_L \qquad (13)$$

Static Power Loss;

$$P_{static} = 0{,}003 \text{ x } V_{in} \qquad (14)$$

Switching Losses of Power Switch;

$$P_{swicth,\,sw} = V_{in} \times I_{Lavg} \times \left(\frac{1}{f}\right) \qquad (15)$$

Core Loss in Inductor. Available in inductor data sheet;

$$P_{core} = \text{from datasheet } 0{,}10 \text{ W} \qquad (16)$$

Saturation Voltage of Power Switch Transistor. Available in inductor data sheet. $V_{sat} = 0{,}1$ V. According to obtained data, in Fig. 11 presents circuit input voltage and circuit total power loss changes. Besides, Fig. 12 shows circuit input voltage and efficiency values changes.
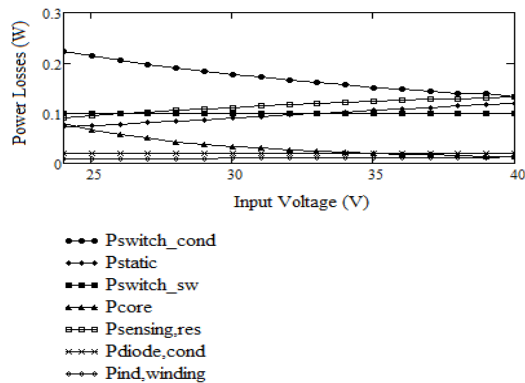

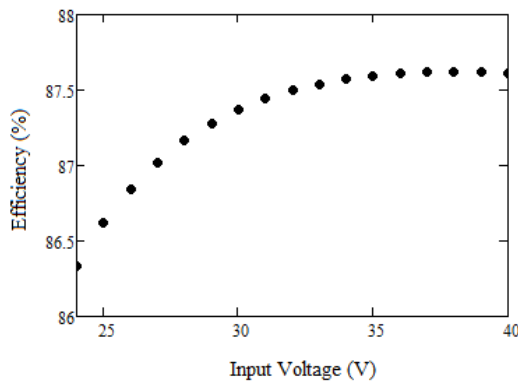*Fig. 11. Experimantal results of the variation of power losses with input voltage*

Fig. 12. Experimantal results of the variation of output efficiency with input voltage

As can be seen in Fig. 14, as circuit input voltage increased, circuit efficiency value increased up to 35V, than it was stabilised. With this regards Fig. 13 shows LED heat and circuit efficiency changes.
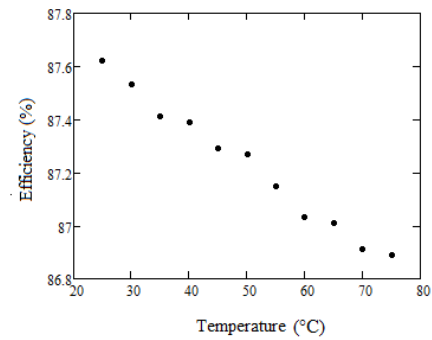

Fig. 13. The variation of output efficiency with temperature

3. Conclusion

This study detected proper driving current in order to make maximum use of LED technology. According to the analyses, the most proper driving current was 320mA. As driving current value applied on LEDs increased, the existence of drooping effect was revealed. The analyses showed that drooping effect was 23.1%. Circuit efficiency values were studied in accordance with driver circuit input voltage changes. The most proper and stable driver circuit was MC34063A switching circuit. Analyses also revealed that heat was an important factor in driver circuit energy efficiency. Driver circuit efficiency values were detected as LED temperature increased. Accordingly, as LED heat increased, circuit efficiency decreased. Obtained data were presented in tables and graphs. Computer software programs, and laboratories were utilized for analyses.

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