JOURNAL OF OPTOELECTRONICS AND ADVANCED MATERIALS Vol. 17, No. 5-6, May – June 2015, p. 816 - 821

Energy optimization of low power LED drivers in indoor lighting

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With the increasing world's population, the need for the energy rises quite fast. From this perspective, restricted energy resources are considered as sufficient to satisfy the energy demand. Taken these issues into account, the resources to meet the energy demand must be created. Furthermore, the existing energy must be used efficiently, which makes the energy saving more important. In this case, the energy saving in lighting is also quite important. The energy consumed for lighting makes up the 20 % of the total consumed electrical energy. With this purpose, more efficient lighting components should be used. Power LEDs are currently manufactured as an alternative lighting source to conventional lighting used at present. A constant current is required for operation of power LEDs. In the present study, the current limited low power LED drivers were examined. For this aim, three different current driving circuits were investigated in terms of their powers. First circuit is a basic driving circuit with a resistance. Second circuit is a LED driving circuit with LM117 regulator, and third one is a current limiting LED driver circuit based on the DC-DC buck converter. Simulations of the current limiting LED driving circuits based on the DC-DC buck converter were prepared. The data from the simulation applications were obtained. Then, the circuit applications were conducted under laboratory conditions. The input current, the total loss, the output power, and the output current of the circuit were measured. The data of output current of these drive circuits were examined in terms of the energy optimization. Efficiencies of these circuits were obtained at the result of simulation and laboratory measurements.

(Received April 10, 2015; accepted May 7, 2015)

Keywords: Power LED drivers, lighting efficiency, energy optimization

1. Introduction

Energy efficiency is defined as the ratio of output power to the total input energy. Improving energy efficiency, the same desired output energy uses less energy to produce [1]. Energy efficiency is one of the most important factors in energy savings. In general, energy saving is perceived as using less energy or as closing one of two bulbs; but these are not always true.

The one-fifth of total energy consumed is used in the lighting systems. For this reason, savings to be made in lighting system and increasing the lighting system efficiency become indispensable.

LED lighting systems have become more important with improving technology. LEDs are mostly preferred because they have many advantages in comparison with other lighting systems. For instance, LED lighting systems provide higher energy efficiency, have long life (approximately 50,000-100,000 hours), require less maintenance, hold little space thanks to the small size of the equipment, provide light and a variety of colors, are more resistant to shock and vibration and have lower power consumption [2].

LEDs were manufactured to be a good alternative to conventional lighting such as incandescent lamps, fluorescent lamps, halogen lamps because LEDs have high light brightness. These LEDs are called power LEDs which are operated at a higher current than standard 5mm LEDs [3, 4]. Therefore, there is a need for special drivers that provide constant current.

In this study, current limiting power LED drivers which have low power were investigated. Three different current driver methods that provide a constant current were examined. These are; simple driving circuit with a resistance, LED driver circuit with LM117 regulator and the current limiting power LED driver circuits based on DC-DC converters.

DC-DC converters are the most efficient among these. Types of DC-DC converters are buck converter, boost converter and buck-boost converter. They can be used as LED drivers. Current limiting driver circuit designs were carried out by selecting DC-DC buck converter. It was the most appropriate LED drive structure for this study. Moreover, the output currents of the different driver circuits were studied. The selected DC - DC buck converter drivers were designed as 1 Watt, 3 Watts and 5 Watts. First time, simulations of designed circuits were conducted. After the simulation, efficiency of the LED driver circuit, the input current, forward voltage of the LED, the total losses, the losses of the LED, the power and the current of the LED driver circuit output were investigated according to different input voltages.

The application of one of the driver circuits simulated was carried out. At the laboratory studies, the power of LED driver, LED current, input current, output power, output voltage, and efficiency of the driver circuit were measured and calculated.

2. LED's (Light Emitting Diode) Structure

Light Emitting Diodes or LEDs are special diodes that convert electrical energy to light energy when a current is applied [4]. The structure and the electrical behavior of LEDs are similar to a rectifier diode [5]. LEDs are made with a combination of semiconductor p-type and n-type materials such as rectifier diodes. They are connected to two terminals called the anode and cathode. When the anode is more positive than cathode, electric current passes through the LED [6].

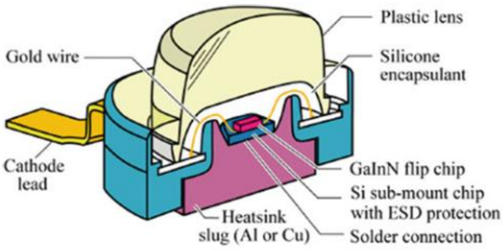


Fig.1. Schematic diagram of high power LED [7].

High power LED packaging use a current more than 350 mA to operate and generate more than 130 lm/W light output [7]. Schematic diagram of the power LED is shown Fig. 1.

Solid-state lighting (SSL) provides more energy saving than compact fluorescent lamps. It is an alternative technology to improve the lighting system. Fig. 2 shows the efficiency of some LEDs in the solid-state structure. Light Emitting Diode (LED) is based on SSL technology [8].

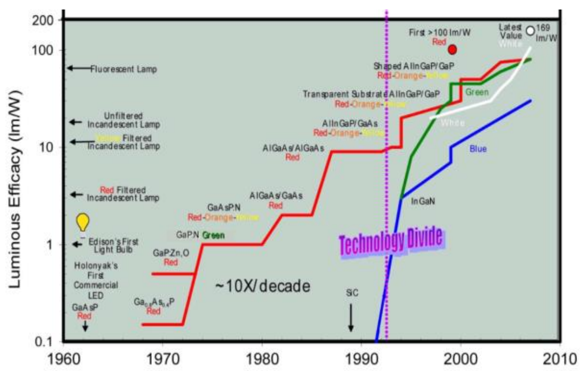


Fig.2. Efficiency of some LEDs in the solid-state structure [9].

When the light sources are compared in terms of application areas, efficiency, dimming control and life time, LEDs are the most efficient lighting technology, which is shown in Figure 3. LED technology evolves and improves performance day by day. Researches show that the efficacy and use of LED lighting technology will increase over the next 10 years.

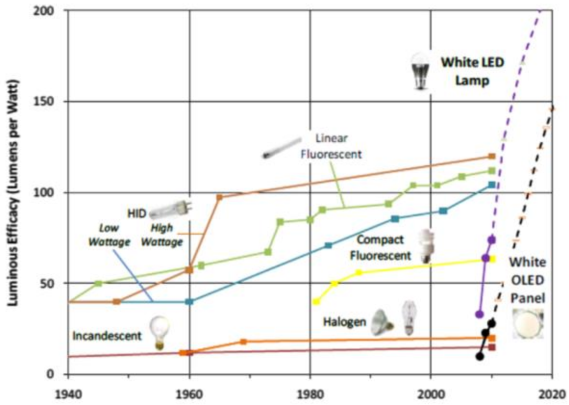


Fig.3. Historical and predicted efficacy of light sources [10].

While the luminous efficiency of LEDs is 80-160 lm / W, the luminous efficiency of other sources is less than LEDs. For example, incandescent lamp has 15-20 lm / W, fluorescent lamp has 50-100 lm / W, and compact fluorescent lamp has 50-70 lm / W. This efficiency will further increase until 2020 as shown in Figure 3. Table 1 shows the efficiency and the lifetime of some light sources [10-11].

Table 1. Lighting efficiency and lifetime of some light sources [10].

Light sources	Illumination Efficiency (lm / W)	Lifetime (hours)
Incandescent	15-20	1000
Tungsten Halogen	12-35	2000-4000
Mercury Vapor Lamps	40-60	12000
Compact Fluorescent Lamp	40-70	6000-12000
Fluorescent Lamp	50-100	10000-16000
Induction Lamp	60-80	60000-100000
High Pressure Sodium	80-100	12000-16000
LED	80-160	50000-100000

3. Experimental

3.1. The Current limiting LED Drivers

3.1.1. The basic drive circuit with a resistance

LEDs require a constant current to work productively. There are a voltage source, three 1-Watt power LEDs, and a resistor for limiting current at the circuit. Fig. 4 shows simple driver circuit with a resistor.

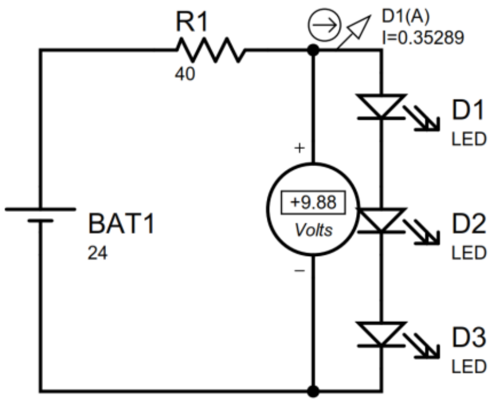


Fig.4. Simple driver circuit.

When the energy is supplied to the circuit, the value of LED current is 0.35 A. LEDs heat up after a period of time and their forward voltage decreases. When temperature has reached a certain degree, the current applied to the LED increases up to 0.39 A. As driver current increases, the LED's heat and energy losses rise. If necessary measures are not taken, LED may deteriorate after some time.

The driver current at a simple drive circuit is given as follows;

$$I = \frac{V_{Source} - V_f * n}{R} \quad (1)$$

where I is the LED current, V_{Source} is the voltage applied to the circuit, V_f is the LED forward voltage, n is the number of LEDs.

Table 2. The results of the simple drive circuit with a resistance

LED Driver's Power	Input Voltage of LED Driver (V)	LED Driver's Efficiency (%)	Output Current of LED Driver (mA)	Output Power of LED Driver (Watt)
1 Watt	12	27	340	1.14
	24	13	342	1.12
3 Watt	12	82	350	3.3
	24	41	350	3.4
5 Watt	12	-	-	-
	24	68	340	5.6

The drive circuits were designed at the various output powers like 1W, 3W and 5W. These circuits were analyzed and the results were given in Table 2. According to the results of the table, the efficiency of driver circuit was higher when the input voltage was low.

3.1.2. LED Driver Circuit with LM117 Regulator

Another LED drive circuit is the one performed with LM117 regulator circuit. LM117 regulator circuit may be used when its input voltage is between 1.2 V to 30 V. Its output currents may be up to 1.5A [12]. LM117 is not suitable for use in high-power LED driver. The output voltage is constant through resistors connected to the adjust terminal. It is denoted in Fig. 5. Approximately 4W - 5 W power is lost at LM117 regulator when the circuit is performed. Therefore, the efficiency of the circuit reduces.

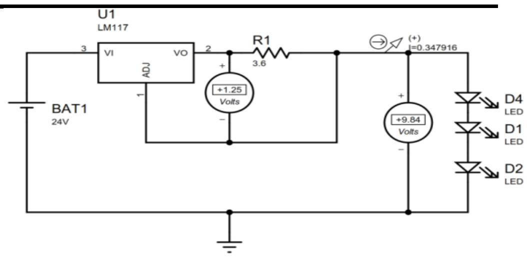


Fig.5. LED driver circuit with LM117 regulator

The circuit output current I_{out} and the reference voltage V_{REF} may be given as follows;

$$I_{out} = \frac{V_{REF}}{R_1 *} \quad , \quad (2)$$

$$V_{REF} = 1.25\ V \ , \ R_1 * = 0.8 \le R1 \le 120 \quad (3)$$

The LED driver circuits were designed using Proteus 8 simulation program. Analyzes of these circuits were performed and the results were given in Table 3. The efficiency of the circuit was higher when input voltage was low according to the results of Table 3.

Table 3 Results of LED driver circuit with the LM117 regulator circuit

LED Driver's Power	Input Voltage of LED Driver (V)	LED Driver's Efficiency (%)	Output Current of LED Driver (mA)	Output Power of LED Driver (Watt)
1 Watt	12	27	350	1.15
	24	14	350	1.15
3 Watt	12	82	344	3.2
	24	41	345	3.3
5 Watt	12	-	-	-
	24	68	355	5.4

3.1.3. The current limiting power LED driver circuits based on DC-DC converters

When the values of input voltage were between 12 V - 24 V and output currents 350 mA - 700 mA, the driver circuit is performed with LM3404. In addition, the various power circuits (1W, 3W, and 5W) were designed and their changes were examined. A typical application of the LM3404 is shown Fig. 6.

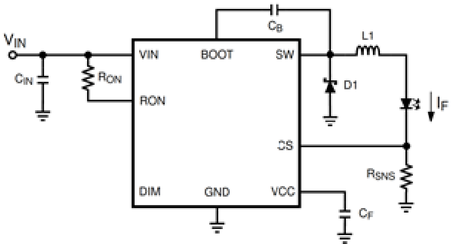


Fig.6. A typical application of the LM3404 [13].

The variations of efficiency, output power (P_{out}), total loss, and LED current of designed circuits were given below.

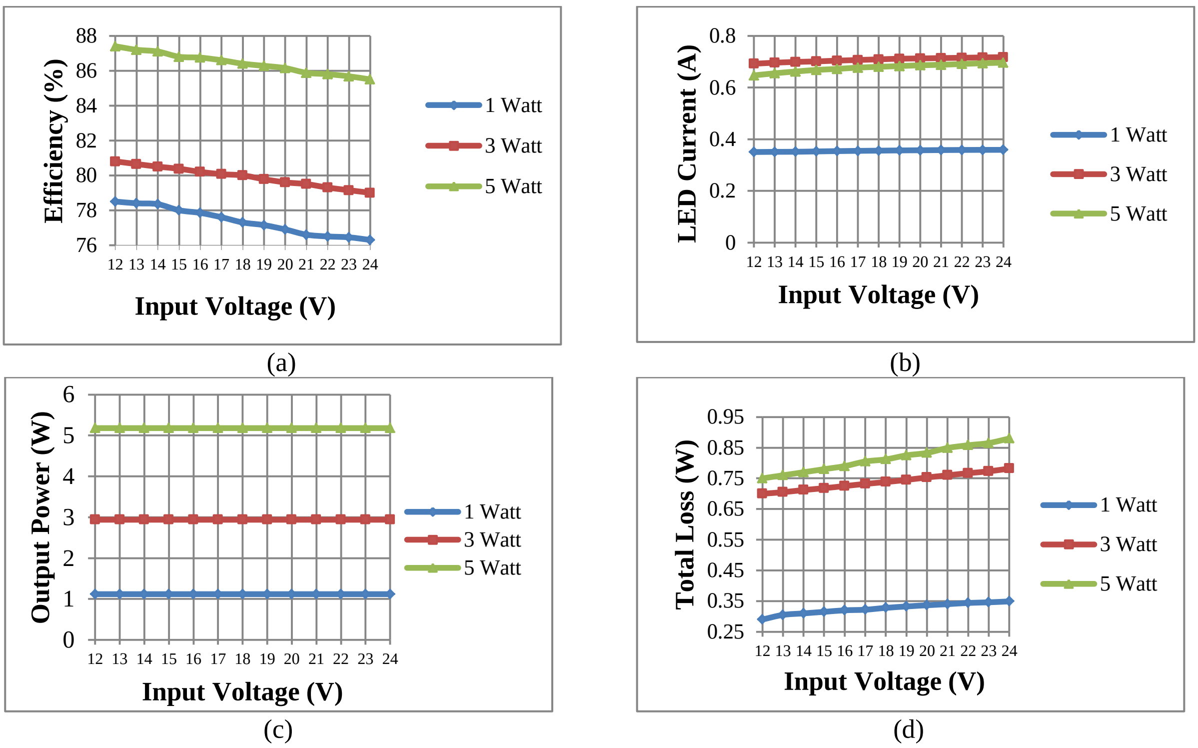


Fig.7. Simulation results of DC-DC buck converter power LED driver (a) Efficiency, (b) LED current, (c) Total losses and (d) Output power

Efficiency is higher when the input voltage is lower. This situation is shown Fig. 7.a. The efficiency rises when the power of the driver circuits is increased. The variation of the LED current according to input voltage is shown in Fig. 7.b. The total loss rises when input voltage and the power of LED driver circuit are increased (Fig. 7.c). Fig.7.d shows the output power of driver circuit. Although the values of input voltage change, the output power is constant.

The simulations of circuits were performed as 1W, 3 W, and 5W. The 5 Watt LED driver circuit was selected as the most efficient one of these circuits. The applications of this circuit were performed under laboratory conditions; the ambient temperature and the relative humidity were 21° C, 60 % respectively. The multimeter used in the laboratory is GDM-8261A. The error rate of the multimeter is 0.0035 %. The current limiting 5W LED driver circuit designed using LM3404 regulator is shown in Fig. 8.

As different input voltages such as 12 V, 18 V, 24 V, 32 V, and 36 V were applied to the power LED driver, the current through the LED, the voltage drop in the LED and input current were measured. After these measurements, the output power and efficiency of the LED drive circuit were calculated. The results of application study are given Table 4.

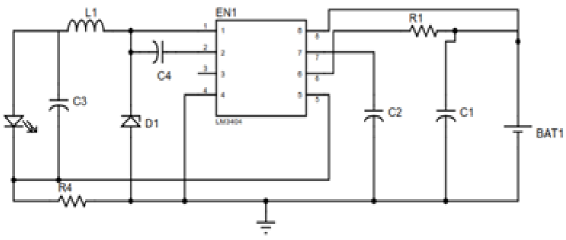
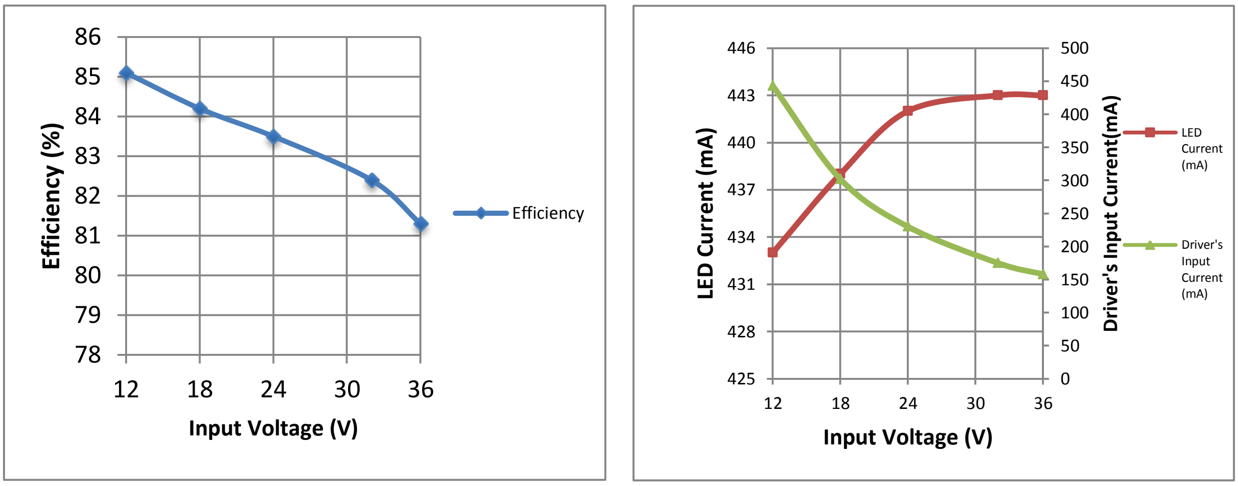


Fig.8. The current limiting 5W LED driver circuit designed using LM3404 regulator

Table 4. The results of application study

Input Voltage (V)	LED Current (m A)	Input Current of LED Driver (mA)	Output Voltage (V)	Output Power (W)	Efficiency (%)
12	433	443	10,45	4,52	85,1
18	438	302	10,45	4,58	84,2
24	442	230	10,45	4,62	83,5
32	443	175	10,45	4,63	82,4
36	443	158	10,45	4,63	81,3



(a) (b)

Fig.9. The results of applications, (a) Efficiency, (b) The change of the input current of the LED driver circuit and LED current according to the input voltage.

The change of efficiency depending on the input voltage is shown Fig. 9.a. As the input voltage increases, the efficiency is observed to be lower. The change of the input current of the LED driver circuit according to the input voltage is shown Fig. 9.b. When the input voltage was increased, unlike the LED current, the input current reduced. At Fig. 9.b, both the input voltage and the LED current increase.

4. Conclusion

Simple LED driver circuit with one resistor, LED driver circuit with LM117 regulator, and current limiting LED driver circuit based on DC-DC buck convertor were simulated. First, when the input voltage of 5 Watt driver circuit with one resistor was 24 V, the output current was measured as 340mA, and the output power was measured as 5.6 Watt. Furthermore, the efficiency of this drive circuit is calculated as 68 %. Second, when the input voltage of 5 Watt LED driver circuit with LM117 regulator was 24 V, the output current was measured as 355mA, and the output power was calculated as 5.4 Watt. There was approximately 4W-5W energy loss in the integrated LM117. Then, the efficiency of this driver circuit was found as the same value; 68 %. Last, the current limiting LED driver circuit based on DC-DC buck convertor was simulated. When the input voltage of this driver circuit was 24 V, the output current was measured as 680 mA, the output power was measured as 5.2 Watt, and the total loss was measured as 0.85 Watt. The efficiency of this circuit was calculated as 86 %. On the other hand, when the input voltage of current limiting LED driver based on DC-DC buck convertor was 12 V, the efficiency increases to 88 %. According to these simulation results, current limiting LED drivers based on DC-DC buck convertor is more efficient than simple LED drivers with one resistor, and LED driver circuits with LM117 regulator. Current limiting LED drivers based on DC-DC buck convertor simulation was conducted in a laboratory setting. When the input voltage of implementation circuit was 12 V, the output current was 433 mA, the output power was 4.52 Watt, and the input current was measured as 443mA. The efficiency of this circuit was calculated as 85 % in accordance with these measurements. When the input voltage was 24V, output current was 442mA, output power was 4.63 Watt, and the input current was measured as 230 mA. The efficiency of this circuit was calculated as 83.5 %. Concordantly, the simulation and the implementation findings show that as the input voltage increases, the efficiency decreases, losses increase, and the output current doesn't change much. 5W LED driver circuits are more efficient according to simulation findings. These efficiency values in question were obtained in terms of energy optimization. Obtained findings and simulated circuit results were compared. In this case, it is seen that simulation and experimental results coincide with each other.

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