Elimination of Electrolytic Capacitor in AC-DC Light Emitting Diode (LED) Driver

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***Abstract*—Advance in Light Emitting Diode (LED) lighting system has created a wider application in an effort to improve conventional lighting system. The existence of electrolytic capacitor in LED driver cause the lifetime of the driver lasted averagely five years while LEDs can stand up to 10 years. This paper discusses on the method used to eliminate electrolytic capacitors by implement the flyback converter as a driver. The proposed topology designed to drive 80W LED lighting system. The converter produces a constant current, 0.7A to drive the LEDs. Besides, in order to obtain a smooth dc output, film capacitor is adopted instead of electrolytic capacitor as a smoothing capacitor. The propose topology, detailed design and operation principle of the main circuit are presented in this paper.**

Keywords-AC/DC LED driver, flyback converter, electrolytic capacitor.

I. INTRODUCTION

Based on Utusan Malaysia dated 7 November 2012, it stated that Malaysian government is together in supporting United Nations in recognizing national achievement in creating lighting system that save energy and does not contribute to pollution. In order to show it support, Malaysia government has decided to ban the use of incandescent bulb. This regulation will be fully effective in two years times [1]. This is in line with the objective of the National Green Technology Policy which was appointed by Ministry of Energy, Green Technology and Water. The objective is to reduce the energy usage and at the same time increase economic growth [2]. The traditional lighting system including incandescent bulbs and fluorescent lamps is using two different mechanisms for converting electrical energy in order to generate light. However, these two types of system currently do not give the best solution in lighting system. Incandescent bulbs give the lowest luminous efficiency because it use only 10% of the electricity to light it up and the rest of the electricity will be converted into heat energy [3]. Fluorescent lamps produce light by converting electrical energy into kinetic energy of moving electrons. The moving electrons collide among themselves thus generate radiation [3]. However, the mercury in this lighting system is dangerous to both human and environment eventhough fluorescent lamps offer a low cost system with high luminous efficiency [3].

At present, LED lighting has a huge potential in replacing the traditional lighting system due to its apparent topographies such as low loss energy, long life time, high luminous efficiency and safe and green [4]. Similar to fluorescent lamp that requires ballast to function, LED lighting also requires driver for the purpose of converting the ac line voltage to a usable energy. LEDs are best operated with constant current based on two reasons. The first reason is to avoid violation of the absolute maximum current rating and to avoid from compromising the reliability of the system [5]. Besides, LED lighting system uses constant current driver in order to achieve predictable and match luminous intensity of each LED [5]. LEDs can last longer up to 50,000 hours compared to other lights including fluorescent lamps which can hold up to 8,000 hours. Nevertheless, there is a problem faced by LED lighting manufacturer which involve its driver system.

Presence of electrolytic capacitors in LED driver is the main problem faced by this system. Electrolytic capacitor is used to produce high value of capacitance on the circuit [6]. In order to do so, one of the plates made of an ionic conducting liquid known as electrolyte is used as to obtain higher capacitance per unit volume [6]. In AC/DC converter, electrolytic capacitor is the element used to stabilize the difference between input pulsating power to the output constant power [7]. In addition, this capacitor is also used to attain low ripple in the DC link [8]. Although electrolytic capacitor gives maximum capacitance per unit volume compared to other types of capacitor such as polyester film and ceramic capacitor, the lifespan of an electrolytic capacitor is a bit short.

The average lifetime of an electrolytic capacitor is 10,000 hours at the temperature around 105°C while the other types of capacitor are above 10,000 hours. The temperature for electrolytic capacitor depends on the use of ionic conducting liquid. As a result, for every 10°C increased, the longevity of the capacitor reduces by half [9]. Consequently, large difference between the LED lifespan and its driver leads to the abolishment of electrolytic capacitor in order to improve the quality of the current lighting system.

The conventional LED driver (Fig. 1) has electrolytic capacitor in order to overcome ripple voltage problem in the system. This will cause the lifespan of the driver to not be the same as the lifetime of LED.

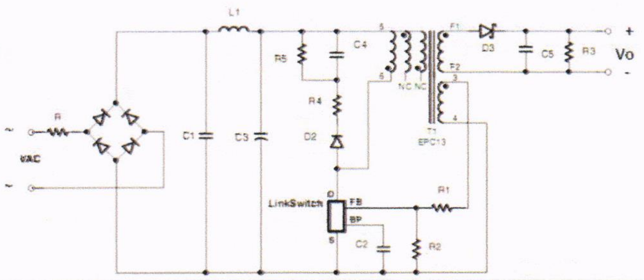
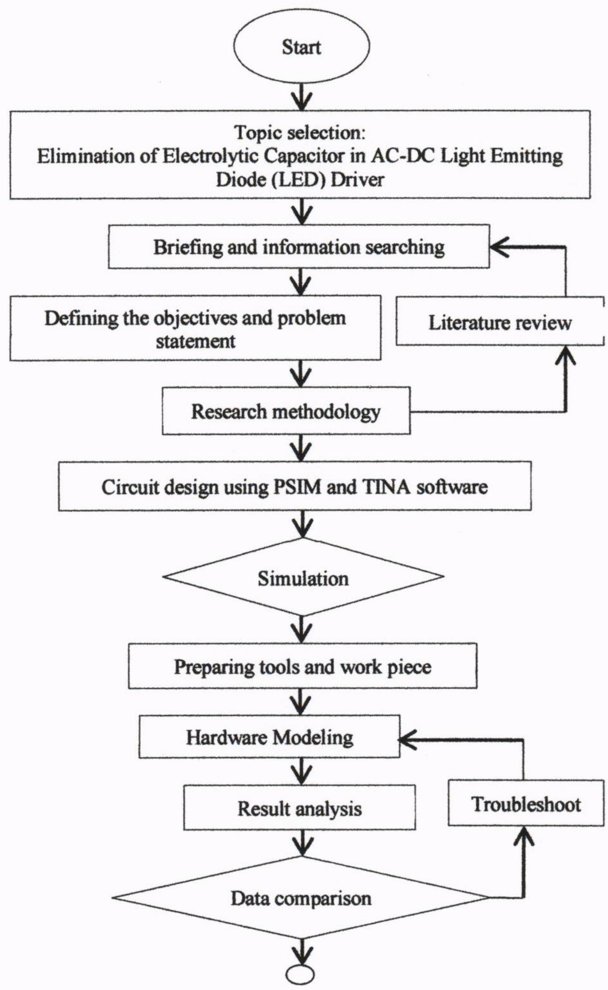
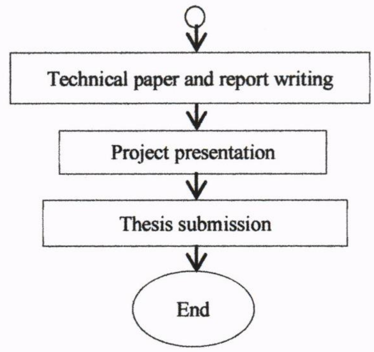


Figure 1. Circuit design for a conventional LED driver

There are many types of AC/DC converter, for example Flyback, Buck Boost, resonant and matrix converter. In this paper, AC/DC flyback converter is chosen to drive an 80W LED lighting system. Flyback converter is a type of AC/DC converter which have inductor split that functions as transformer. Hence, flyback converter is one of the isolated converters. Besides that, flyback converter also has a wide input voltage range because of the presence of transformer since the operation relies on the energy stored in it.

II. METHODOLOGY





The aim of this paper is to deal with problems associated with electrolytic capacitors which currently give negative impact to the whole LED lighting system. In order to uncover the objective of this project, literature review has been made to identify the real problems associated to the current LED lighting system.

In addition, the other technique used is reviewing all material related to the topic to enhance the knowledge about the project and problems encountered. Among the material used includes books, journal and technical paper from various professors from various universities and articles from web that discuss on electrolytic capacitor, LED lighting system, LED driver and problem faced by the system.

After identifying the problem related to the electrolytic capacitor in the driver circuit, new AC/DC flyback converter is selected for the purpose of driving the 80W LEDs. Electrolytic capacitor which was used as a smoothing is replaced by polyester film capacitors connected in parallel to increase the value of the polyester capacitor. Equation (1) is the calculation for parallel connected capacitors. The circuit is simulated using PSIM and TINA software which are the tools used to analyze, design and simulate circuits for power electronics and motor control.

The next step is modeling the software simulation by preparing tools and work space. The hardware prototype obtained the similar result achieved by the simulation part. Troubleshooting is done when there is any difference in the results achieved in hardware part compared to software simulation.

III. BASIC OPERATION OF FLYBACK CONVERTER

Flyback converter with transformer is very popular for power supply designs below 100W to 150W. The advantages stated above made this converter fit the design procedure to drive LEDs. Fig. 2.1 shows the basic circuit design for a flyback converter.

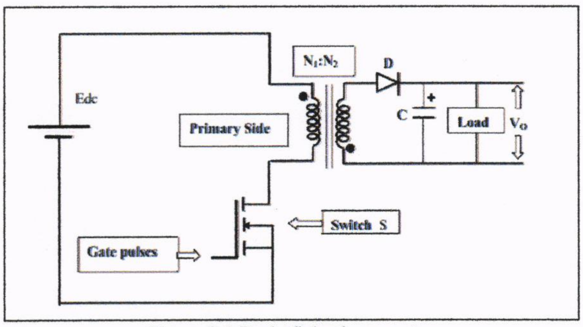


Figure 2.1 Basic flyback converter

The schematic of a flyback converter is constructed by buck-boost converter and is added with an inductor split, in which one is a primary side and another one is a secondary side that represents a transformer [10] [11]. During the switch on condition, current increase in the primary winding and magnetic energy is stored in inductor, L_1 [11]. During switch off condition, the only way for the primary inductor, L_1 to transfer the energy stored since the transformer wants to sustain the magnetic flux is by inducing voltage to the secondary side of inductor, L_2 [12]. Now, the voltage at the secondary side is high enough to forward bias the diode, D.

Flyback converter has different circuit configuration for each of its operation. Assume that the MOSFET is used as a switch. Fig. 2.2(a) shows when switch is closed (Mode-1), the current at the primary side rises linearly when the input supply voltage appears across the primary winding inductance, L_1 [13]. The current in the magnetizing inductor increases from zero until its proportional to the instantaneous AC line voltage [3]. This causes voltage induce over the secondary winding and the polarity as indicated [12]. Thus, diode is now in reverse biased condition. The secondary side currently can be assumed not connected as no current appears on that side [12].

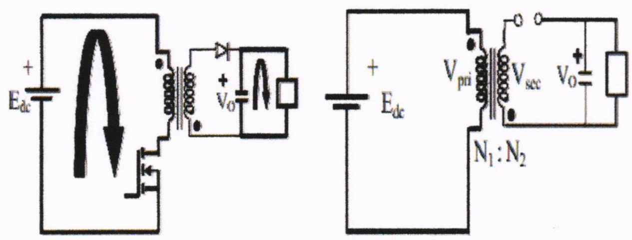


Figure 2.2(a) Equivalent circuit and current path during Mode-1

Mode-2 of the circuit operation starts when the switch is open after conducting for some time. The primary path is now is not completed and cause the voltage polarities across the secondary windings reverse [13]. Diode is now in forward biased and allows current flow in secondary part of the converter as shown in Fig. 2.2(b).

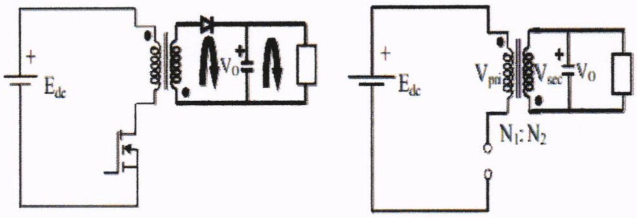


Figure 2.2(b) Equivalent circuit and current path during Mode-2

In discontinuous conduction mode, see Fig. 2.2(c), diode which connects in series with the winding will stop conducting because of both the emf at the secondary winding as well as current reduce to zero. This happens after the magnetic field energy completely transfers to the output [13]. Yet, the load continues to produce a steady voltage. This is due to the relatively large output filter capacitor [13].

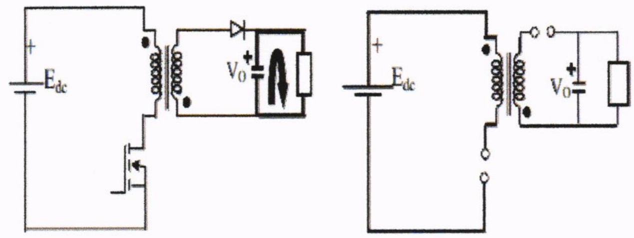


Figure 2.2(c) Equivalent circuit and current path during Mode-3

IV. CIRCUIT DESIGN

An AC/DC flyback converter has been designed to drive an 80W LED lighting system. The input supply is 240V ac and the desired output to drive the system is 110V and 0.7A. As shows in Fig. 3.1, the designed converter is using inductor split to reduce the voltage from 240V to 120V. This element acts as a step down transformer. In addition, in order to achieve the objective of this research, the electrolytic capacitor is replaced by polyester film capacitor. Although the capacitance value of polyester film capacitance cannot compete of the electrolytic capacitor, it can be achieve by connecting the polyester film capacitors in parallel. As basic circuit operation, connecting capacitor in parallel can increase the value of capacitance. This is proved by Eqn. 1.

$$C_T = C_1 + C_2 + C_3 \qquad (1)$$

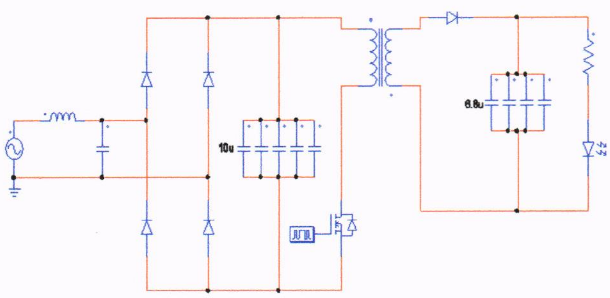


Figure 3.1 AC/DC flyback converter with elimination of electrolytic capacitor

As flyback converter requires a switch to operate, MOSFET is connected to the primary side of the circuit and this element controlled by pulse width modulation (PWM) signal. The switching period for this circuit is set to 0.02ms with switching frequency 50kHz. In order to have a constant voltage during switching cycle, switching frequency of flyback converter is designed to be much greater than the AC line frequency [3].

As AC/DC converter contribute to ripple in the both voltage and current, it had been set that the acceptable ripple for the output current is only 8% of the desired value. These calculations determine the range for output current that able to drive the lighting system.

$$I_{min/max} = I_o - \left(\frac{8}{100} \times I_o\right)$$

Thus,

$$0.644A \leq I_{dc} \leq 0.756A$$

Hence, the output voltage is in the range between 101.2V until 118.8V and the adequate value of current that enough to drive this lighting system is between 0.644A to 0.756A.

V. RESULT AND DISCUSSION

The designed circuit is simulated by TINA software in order to determine whether the circuit fulfilled all requirements to drive 80W LED lighting system. The line inductor, L and capacitor C_1 is connected to the ac side and functioned as a filter and eliminate the distortion appear in the input current. Fig 3.2(a) and (b) shows the input current waveform respectively before and after the LC filter.

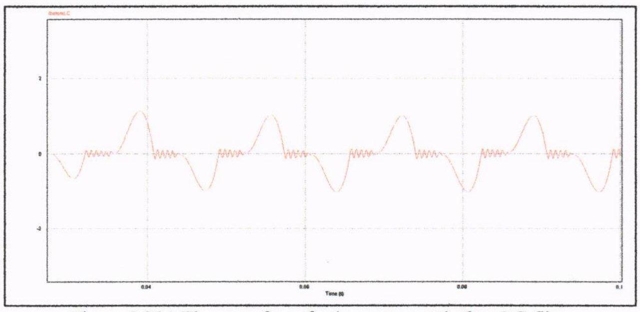


Figure 3.2(a) The waveform for input current before LC filter

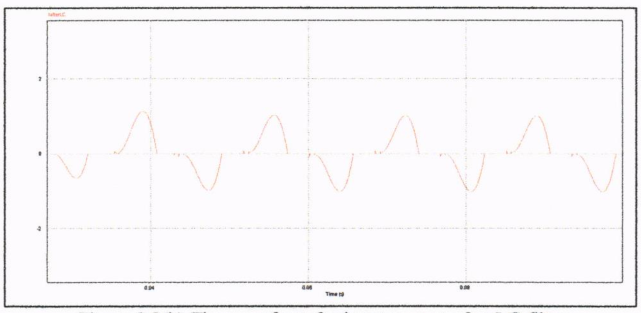


Figure 3.2(b) The waveform for input current after LC filter

Capacitor C_2 and C_3 indicate the total value of five 10µF and four 6.8µF polyester film capacitors connected in parallel respectively.

TABLE I. CIRCUIT PARAMETER

Input voltage	240V ac, 50Hz
Switching Frequency, f_s	50kHz
Output voltage	110V
Output Power	80W
Turn ratio 1:n, a	1:0.5
Resistor, R	150Ω

By referring to Fig. 3.3, the output voltage is 118.26V and the output current is 0.739mA. Table II. show the values for both voltage and current flowing through the designed circuit.

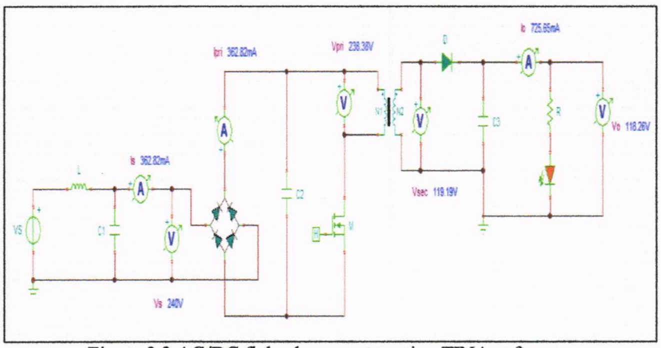


Figure 3.3 AC/DC flyback converter using TINA software

TABLE II. VOLTAGE AND CURRENT VALUE USING TINA SIMULATION

Input	Output	Primary	Secondary
240V ac	118.26V dc	238.38V	119.19V
0.3696A	0.7391A	0.3696A	0.7391A

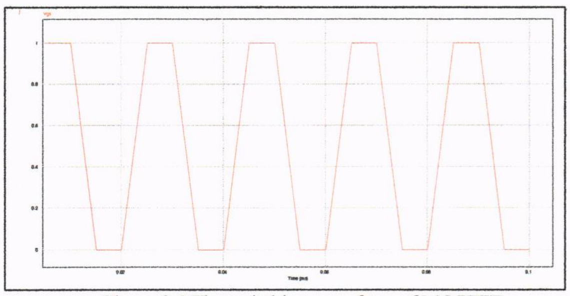


Figure 3.4 The switching waveform of MOSFET

Figure 3.4 shows switching waveform of the MOSFET. The switching period of the MOSFET is 0.02ms.

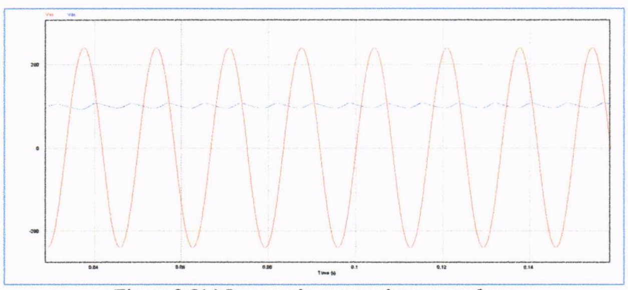


Figure 3.5(a) Input and output voltage waveform

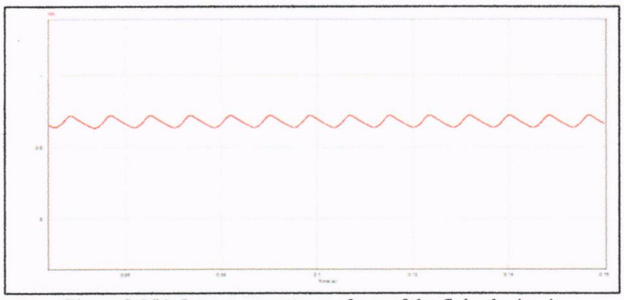


Figure 3.5(b) Output current waveform of the flyback circuit

Figure 3.5(a) indicates the input and output voltage waveform for the flyback converter. The ripple output voltage is between 95V to 108V. LED driver is an AC/DC converter which requires constant current output to drive LEDs. In Fig. 3.5(b), it is clearly illustrated the output current waveform that gives 0.64A and 0.72A as the minimum and the maximum output current respectively. Table III demonstrate the average and RMS value for both output voltage and current. The values obtained using Psim software.

TABLE III. AVERAGE AND RMS VALUE FOR OUTPUT VOLTAGE AND CURRENT

	Voltage, V	Current, I
Average	107.46V	0.716A
RMS	111.23V	0.742A

The most difficult part in designing flyback converter is the transformer. In this project, finding a suitable transformer is hard since the suppliers normally have a few types of transformer in their stocks. However, the primary, L_p and secondary magnetizing inductor, L_s can be determined using Eqn. (2) and (3) by assuming V_d is 0.7V and V_m is 10V [14].

$$L_p = \frac{V_s \times D}{f_s \times I_p} \tag{2}$$

$$L_p = L_s N_{ps}^2 \tag{3}$$

where I_A and I_p is the average and peak MOSFET current respectively. I_p that can be calculate using Eqn (5).

$$V_s = \frac{V_o + V_d}{a} = 221.4V \tag{4}$$

thus,

$$P_{in} = V_s I_s = 10 I_A + V_d I_o + P_o \tag{5}$$

Substituting $I_A = I_S$ in Eqn (5) gives

$$I_s = \frac{80.49}{201.4} = 0.399A$$

$$I_p = \frac{2I_s}{D} = 1.6A \tag{6}$$

Hence, by substitute I_p in Eqn. (2), the primary magnetizing inductor is 1.39mH.

VI. CONCLUSIONS

In spite of the long lifetime of LEDs, the relatively short lifetimes of the LED driver due to the existence of electrolytic capacitors in the driver circuit limit the lifespan of overall LED lighting system. In order to solve this problem, an AC/DC flyback converter without electrolytic capacitor is designed to drive the 80W LEDs. The electrolytic capacitors have been replaced by polyester film capacitors which connected in parallel for the purpose of smoothing the output voltage and current. The desired output current, 0.7A and voltage; 110V was successfully achieved within the acceptable ripple value. The circuit operation, features and results have been illustrated in this paper. The simulation results prove that the proposed topology works as a good solution that can be implemented since there is a high demand from consumers. Apart from that, its advantageous features which are long-lasting, high brightness and reliable is seen as good solution in replacing the traditional lighting system for residential area, heavy industry and even hard and dangerous zone.

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