International Journal of Power Electronics and Drive Systems (IJPEDS)
Vol. 14, No. 4, December 2023, pp. 2328~2337
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v14.i4.pp2328-2337

Switch mode power supply with flyback LED driver topology in public lighting systems energy supply

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Article Info

Article history:

Received Jan 26, 2023
Revised Apr 20, 2023
Accepted May 3, 2023

Keywords:

Constant current
Constant voltage
Flyback
High-frequency switching
Street lighting system
Switch mode power supply
LED driver

ABSTRACT

This research aims to design a flyback topology switch-mode power supply constant voltage and constant current light emitting diode (LED) driver to improve the performance of the LED. The flyback topology is chosen for its simple design and small size and uses high-frequency switching to lower the high DC voltage from the power source. The research aims to avoid blackouts caused by a drop in the power source voltage and to produce technological products that can be developed for other lighting applications. The constant-voltage feedback system ensures that the current flowing to the LED remains stable despite changes in load or other conditions. When there is a voltage drop from the power source, this topology can maintain the voltage and current stable and in accordance with the working voltage specifications of the LEDs. According to test results, the LED driver's output voltage ranges from 18.03 to 18.06 volts with an average message error value of 0.3%. In this system, switching occurs at frequencies ranging from 18.041 Hz to 38.230 Hz. With a constant current value of 0.58 ampere, the resulting lamp's lux value is stable and does not significantly change.

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1. INTRODUCTION

Light emitting diode (LED) is a type of semiconductor that converts electrical energy into light [1]. One of the main fields of implementation for LED lights is public transportation for general road lighting. Public road lighting is essential in ensuring safety for road users, especially at night. With advancements in lighting technology, LED lights offer many advantages over other types of lights, such as high efficiency, longer lifespan, and better energy savings [2]. Power supply circuit is required as an energy converter since LEDs operate on direct current (DC) voltage, while the electricity supplied by the utility company is AC (alternating current) [3]. However, the implementation of LED lights for public road lighting still has some issues that affect the function and optimal performance of the lights. One factor affecting the durability and optimal performance of the lights is the electricity condition on the distribution lines [4]. The electricity from the utility company on the distribution lines is used as the energy source for LED public road lights. The voltage of the electricity can fluctuate according to the load and equipment being used. The condition of the LED energy source on transmission and distribution networks generally experiences a voltage drop that is directly proportional to the length of the channel and load [5].

A switch mode power supply (SMPS) circuit, based on Figure 1, is an electronic device that converts an incoming alternating current (AC) power into a regulated direct current (DC) power output [6]. The primary function of an SMPS is to convert the incoming AC power into the regulated DC power output that is required for the electronic device it is powering [7]. The SMPS also provides isolation between the input and output, protecting the electronic device from voltage transients or other power disturbances. The main components of an SMPS include a switching device, such as a transistor or an insulated-gate bipolar transistor (IGBT) [8]; a filter, such as an inductor or a capacitor; a control circuit, a transformer, a rectifier, a filter capacitor, and a protection circuit. The switching device converts the incoming AC power into a high-frequency AC waveform. The filter smooths the high-frequency waveform and converts it into the desired DC voltage level [9]. The control circuit monitors the output voltage and adjusts the switching device accordingly to maintain the desired output voltage level. The transformer steps down the voltage level and isolates the input and output. The filter capacitor suppresses high-frequency voltage ripple and noise [10]. The protection circuit limits the current and voltage to prevent damage to the electronic device and the SMPS.

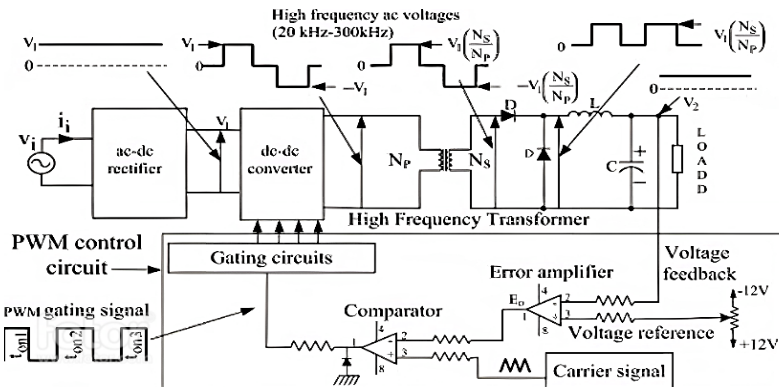


Figure 1. Block diagram of an active mode power supply with a high-frequency transformer [11]

Several studies discuss LED drivers. These studies highlight the importance of earlier designing and implementing LED lights for public road lighting efficiently and effectively. They propose solutions such as LCL filters and smart control algorithms to improve the lights' performance and energy efficiency while also ensuring road users' safety and security [12]. The studies also demonstrate the importance of considering various factors such as resonant frequency, maximum current ripple, and ambient light level when designing and implementing LED lights for public road lighting [13]. By considering these various factors and implementing solutions to address them, the LED lights can provide optimal performance and energy efficiency while reducing the environmental impact [14]. LED drivers can be implemented using a variety of topologies, such as buck converters, to maintain a constant output voltage [3]. A fuzzy control system can then be added to improve the performance of the output voltage stability level [15], [16]. The use of DC voltage and simulation software is still dominant in previous studies with the aim of an LED driver that produces a constant voltage. The flyback topology can maintain a constant voltage and current level, which is necessary to ensure the stability and longevity of the LED lights [17]. Additionally, it can reduce harmonic distortion, which causes unwanted electromagnetic interference (EMI) and affects the performance of other electronic devices [18]. This study's use of an AC source makes it interesting because it enables the development of an LED driver that can maintain constant voltage and current despite a voltage drop.

2. METHOD

The public lighting system cannot stand alone without any relationship with other electrical systems. The electrical energy source used for public lighting is generally from the State Electricity Company (PLN) source that comes from a 220 V distribution transformer. The researcher focuses on the flyback-topology-based LED Driver component, essential for converting PLN electrical energy from alternating current (AC) to direct current (DC) to satisfy LED lamp requirements. The function of converting from AC to DC must be accompanied by the efficiency and stability of electrical energy output to improve lamp efficiency and maintain voltage and current output stability so that the lamp can last longer [19]. The load specifications will be used as a reference for designing the LED driver. The load to be used is the result of research entitled "Prediction of Led Arrangement Illumination on Street Lighting System Armature Using Random Forest Regression Method" [20].

2.1. Flyback topology

In the design of a LED street lighting driver, the researcher uses the flyback topology as the primary type that will be used to adjust the specifications of the LED lamp. In this topology, a transformer converts the input voltage into the desired output voltage [21]. Due to their low element count, straightforward operation, and isolation between the input and output, flyback converters are frequently used in low-voltage applications [22]. The working principle of this topology is to convert the DC input current into an AC current through the switching transistor and then pass it to the primary winding of the transformer. When the transistor is switched on, the current flows from the input to the primary winding transformer and induces a voltage on the secondary winding. When the transistor is switched off, the current flowing in the primary winding transformer will be hindered by the capacitor connected to the primary winding transformer, which will induce a voltage on the secondary winding that will flow to the output [23]. The current generated from the secondary winding is then converted into the desired DC output voltage through the rectifier and filter process [24]. The flyback converter circuit using the feedback system is shown in Figure 2.

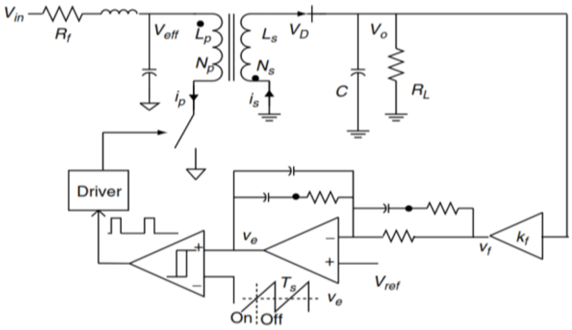


Figure 2. Flyback converter with voltage-mode control [25]

The advantage of this topology is that it is quite efficient and compact, as it does not require two switching transistors like the buck-boost topology [26]. The leakage current can cause energy loss and unwanted heat, while the unstable voltage can cause problems with the output component [27]. Therefore, a good design and accurate calculations are required to overcome these problems.

2.2. LED load specification

The specific requirements of the LED Driver must be adjusted to the specifications of the LED lamp that will be used for public lighting needs. In this research, the lamp specification that will be used is an LED lamp with 18 pieces arranged in series and parallel. The circuit diagram of the LED chip arrangement is explained in Figure 3. The specifications for each LED chip can be seen in Table 1. The LED circuit's arrangement will affect the LED lamp's voltage and current. If the LED chip is arranged in series, the working voltage will increase, while if the LED chip is arranged in parallel, the current will become more significant. The LED lamp array is placed in series, with six pieces in each series, each set in parallel.

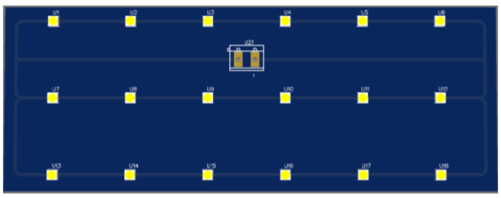


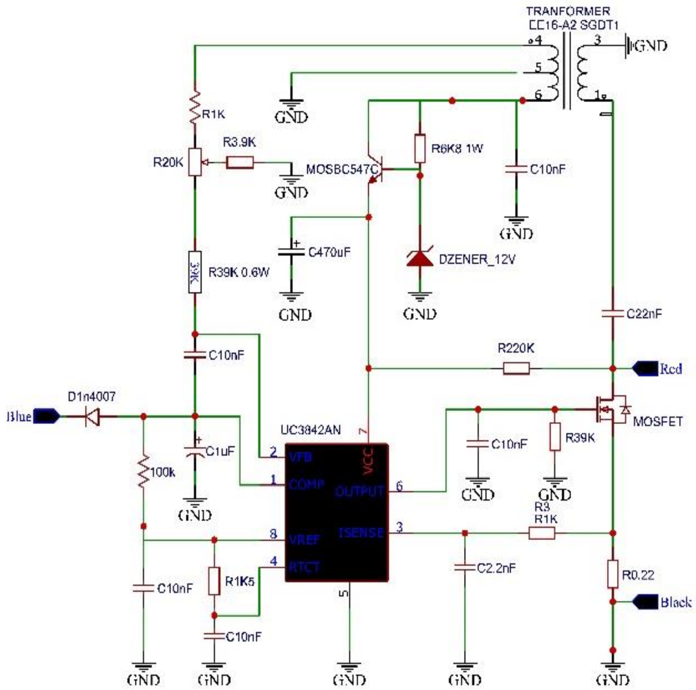
Figure 3. The array of LED lights

Table 1. The proposed LED load specification [20]

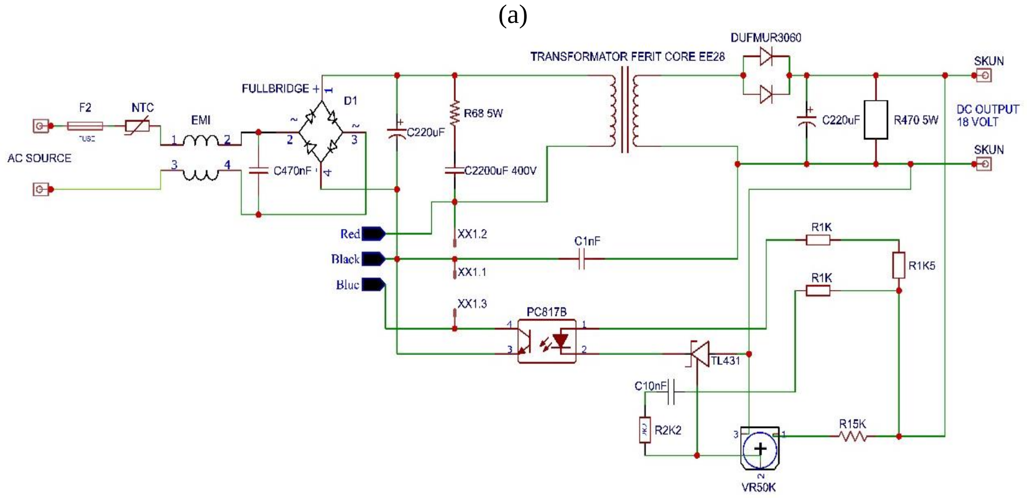
Type	Chip Brand	Color	DC Voltage (volt)	Dimension (mm)	DC Current (mA)	Lumen/Watt (lm)
1W SMD 3030	Philip 2×1734 mil	White 6000-6500 K	2.9-3.2	3.0×3.2×0.65	300-350	110-130

2.3. Proposed flyback LED driver

The researcher proposed a circuit design consisting of two parts: a PWM generation system utilizing UC3848 AN IC, as illustrated in Figure 4(a), and a primary electrical design system for the LED driver employing a flyback topology, with component details and corresponding values displayed in Figure 4(b). The conversion process is not enough to change the type of AC power to DC power. Some supporting systems, such as filters, feedback control, and transformer, are required to ensure that the voltage produced is to the specifications of the LED lamp that will be used as a load. Figure 5 displays the details of the parts of the driver LED that have been designed.



(a)



(b)

Figure 4. Proposed schematic design: (a) UC3848AN oscillator circuit design and (b) flyback topology LED driver circuit design

2.4. Data collection method

The experimental setup used to evaluate the LED driver's performance and quality is crucial for accurate assessment. The setup consists of a voltage regulator for varying the input voltage from the PLN AC source, a multimeter for measuring the input current, output current, and output voltage from the LED driver, an oscilloscope for measuring the switching frequency of the signal generator by observing the waveforms of the signals generated by the driver, and a lux meter for measuring the lux value of the LED light produced by the driver, shown in Figure 6. During testing, these instruments are used to adjust the input voltage, measure the current and voltage flowing through the driver, observe the switching characteristics of the driver, and calculate the lux value of the LED light produced. These instruments ensure that the testing is precise and that the LED driver's performance and quality are accurately evaluated.

It is crucial to analyze the variable data collected during testing to evaluate the performance and quality of the LED driver. These variables include the input voltage, the input current, the output current, the output voltage, the switching frequency, and the lux value. The input voltage is varied using a voltage regulator, and the multimeter measures the input current, output current, and output voltage. The switching frequency is measured with an oscilloscope, while the lux value is measured with a lux meter. These variables are recorded for each measurement to assess the performance and quality of the driver accurately. The input voltage is necessary for determining the driver's efficiency, whereas the input current is necessary for determining the driver's power consumption. The output current and output voltage are crucial for determining the driver's capability to regulate current and voltage. The switching frequency is essential for evaluating the switching characteristics of the driver, whereas the lux value is required for determining the performance quality of the LED driver. It is possible to optimize the design of the LED Driver for specific applications and improve its performance and quality by analyzing these variables.

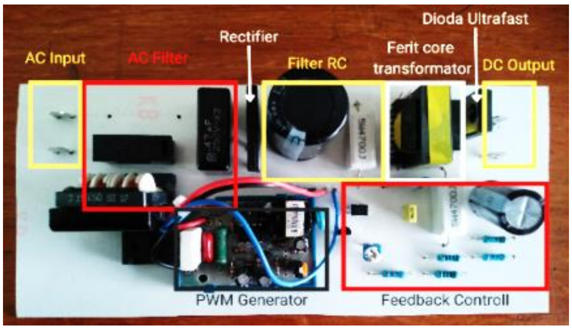


Figure 5. Parts and components of the SMPS driver LED system

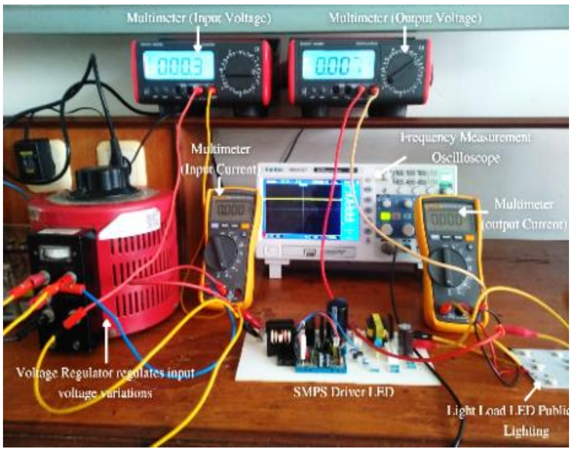


Figure 6. Driver testing setup of LED driver

3. RESULTS AND DISCUSSION

The research results that have been conducted will be discussed in this chapter by displaying the process of data collection and processing. This research was conducted in the electric energy conversion laboratory of the Faculty of Engineering at the University of Jember. This study aims to develop a switch mode power supply driver LED with a flyback topology to consistently achieve a DC output voltage of 18 V with a constant current. The topology and circuit design, as well as the values of the components used in this research, have been determined with some tolerance adjustments for errors that occur during the implementation phase. The components include a bridge rectifier diode with a 220 μF capacitor filter and a 68-ohm 5-watt resistor. The ferrite core transformer used has 40 primary turns and four secondary turns. The type of ferrite core used is the EE 28 type with dimensions. A pulse width modulation (PWM) generator circuit uses the UC3848AN IC. The voltage feedback control circuit is used to keep the output voltage constant. This circuit uses the TL431 voltage reference IC, which can auto-track voltage adjustments and current control.

3.1. LED driver testing

The measurements that are conducted include the measurement of voltage, current, and frequency. The input voltage of the LED driver is varied using a voltage regulator. The voltage and current flowing in the driver are measured using a multimeter. An oscilloscope is used to measure the switching frequency of the signal generator, with the probe positioned on the primary side of the ferrite transformer. Then, on the output side of the driver that has been connected to the LED load, the output voltage and current of the switch mode power supply driver LED are also measured. The following is Table 2, which shows the results of the testing and measurements that have been conducted. The output voltage produced by the LED driver ranges from 18.03 volts to 18.06 volts from the measurement results with the variations made on the voltage source using the voltage regulator. The following is Figure 7, a graph that shows that the voltage produced is following the setpoint voltage with a small average error value of 0.3%.

Table 2. SMPS LED driver test result data

No	Input voltage (Volt)	Input current (Ampere)	Output voltage (Volt)	Output current (Ampere)	Set point output (Volt)	Error (%)
1	220	0.137	18.03	0.57	18	0.17
2	210	0.132	18.05	0.58	18	0.28
3	200	0.135	18.05	0.58	18	0.28
4	190	0.136	18.05	0.58	18	0.28
5	180	0.146	18.05	0.58	18	0.28
6	170	0.151	18.05	0.58	18	0.28
7	160	0.154	18.06	0.58	18	0.33
8	150	0.162	18.06	0.58	18	0.33
9	140	0.166	18.06	0.57	18	0.33
10	130	0.187	18.06	0.57	18	0.33
11	120	0.261	18.06	0.57	18	0.33
12	110	0.245	18.06	0.57	18	0.33
13	100	0.211	18.06	0.57	18	0.33
		Error average (%)				0.30

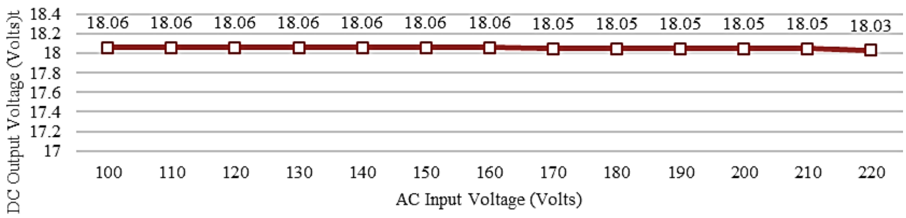


Figure 7. Graph of the results of the LED Driver output voltage test against changes in input voltage

The graph in Figure 7 demonstrates that the performance of the designed LED driver allows it to maintain a constant output voltage following the established setpoint voltage. The voltage feedback readings that produce the constant voltage are then processed by the TLP 341 as a result. The TLP431 component is an electronic part used in a constant voltage feedback system as a voltage reference controller. Its purpose is to modify the system's output voltage per the designated reference voltage to maintain the output voltage's consistency despite changes in load or other circumstances. As a result, TLP431 aids in preserving the output voltage's stability in the constant voltage feedback system. By adjusting the resistance value in the feedback control circuit, the settings are made to determine the setpoint output voltage. The modified resistance value will generate the required reference voltage based on the modified value of the variable resistor.

3.2. Testing the effect of switching frequency

Flyback topology, with a ferrite transformer connected in series with the LED and activated by a pulse signal controlled by a PWM signal generator control circuit, was used in the design of this SMPS LED driver. Because ferrite is an essential material and is used to make transformers, high frequency is needed to make ferrite transformers operate at a given frequency. High magnetic permeability and low magnetic resistance are the magnetic material ferrite characteristics. In contrast to magnetic reluctance, which measures how difficult it is to change magnetization, magnetic permeability measures a material's capacity to flow magnetization. Since ferrite material has a low magnetic reluctance at low frequencies, magnetization can be easily altered. However, the magnetic reluctance of ferrite material increases at higher frequencies, making magnetization more challenging to modify. As a result, at higher frequencies, ferrite transformers will operate more effectively. The results of testing the impact of frequency on input voltage changes are shown in Table 3. Table 3 and Figure 8 can be obtained, which explain the graph of the relationship between frequency and voltage changes that have been varied.

Based on Figure 8, it can be deduced that the frequency that has been controlled will increase the lower the value of the AC source voltage that enters the LED Driver. Due to the fundamental properties of the ferrite material used in manufacturing transformers, the ferrite transformer operates with frequency. A type of magnetic material called ferrite has a low magnetic reluctance but a high magnetic permeability.

Because the constant voltage conversion LED driver flyback topology uses a resonance system to convert AC voltage into the DC voltage needed by the LED, the output frequency of this topology will rise as the input AC source voltage falls. A transformer and a capacitor are connected in parallel to create this resonance system, which generates a constant voltage cycle. The output frequency of the driver will rise to maintain a constant output voltage when the input voltage falls because this voltage cycle also decreases with the input voltage. This is how the flyback topology maintains output voltage stability, but the higher frequency can result in issues like increased heat and electromagnetic interference.

Table 3. Data testing the effect of switching frequency

No	Input Voltage (Volt)	Input Current (Ampere)	Output Voltage (Volt)	Output Current (Ampere)	Switching Frequency (Hz)
1	220	0.137	18.03	0.57	18041
2	210	0.132	18.05	0.58	18698
3	200	0.135	18.05	0.58	19094
4	190	0.136	18.05	0.58	19631
5	180	0.146	18.05	0.58	20180
6	170	0.151	18.05	0.58	22578
7	160	0.154	18.06	0.58	27868
8	150	0.162	18.06	0.58	30574
9	140	0.166	18.06	0.57	32378
10	130	0.187	18.06	0.57	33980
11	120	0.261	18.06	0.57	35535
12	110	0.245	18.06	0.57	37069
13	100	0.211	18.06	0.57	38230

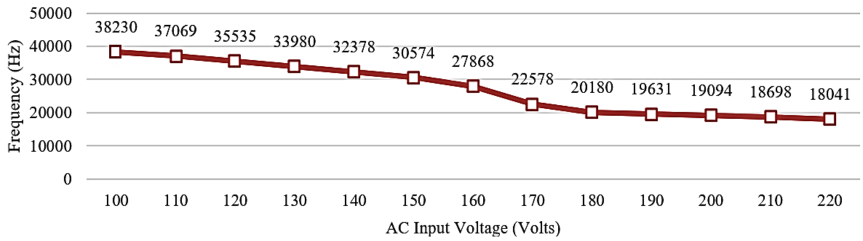


Figure 8. Graph of the relationship between switching frequency and changes in input voltage

3.3. Electrical current testing

The current characteristics obtained from testing the LED driver to maintain voltage stability can be analyzed in Figure 9. The characteristics of the LED driver's input and output current are shown in Figure 9. The input current from the AC source must be increased when the AC source voltage is reduced to maintain the stability of the LED driver's output voltage because the output voltage from the LED driver will fall if the input voltage from the AC source also falls. This is because the LED driver, which transforms AC voltage into the DC voltage needed by the LED, operates fundamentally. Transformers and diodes are used by the LED driver to carry out this conversion, and how well they work depends on the voltage that enters the driver. Due to the constant voltage feedback system at work on the LED driver, the current flowing at the output of the LED driver is comparatively steady. Regardless of changes in load or other circumstances, the constant voltage feedback system ensures that the current flowing to the LED remains stable. A voltage reference controller regulates the current flowing to the LED in a constant voltage feedback system following the designated reference voltage. To maintain a constant output voltage, the voltage reference controller will adjust the current to the LED if the output voltage rises or falls. As a result, the current going to the LED will also not change.

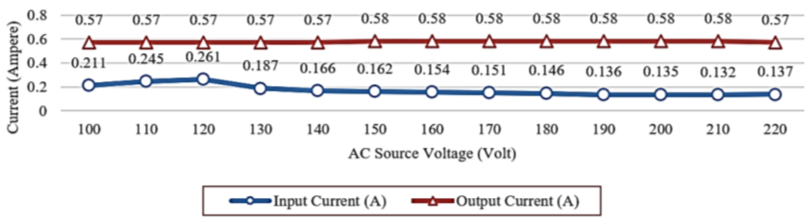


Figure 9. Characteristics of the input current and output current in the LED driver

3.4. Testing the effect of voltage changes on the lux value

Testing the value of lux from the LED as a load is intended to determine the effect of voltage changes on the lux or light intensity generated by the lamp. In the testing, a distance of 1 meter is used between the lamp and the lux meter, and the input voltage variations used are the voltage range of 220 volts to 100 volts. The testing illustration can be seen in Figure 10.

Figure 10. Electronic circuit testing the lux value of LED lights

Figure 10 illustrates the circuit for testing the lux value of the LED lamp. The data obtained from the lux value of the lamp is displayed in Table 4. The comprehensive data of the lux value of the light received is then calculated, and the average is calculated. Then the mean absolute error (MAE) value obtained is 1.514, which indicates a good value because the change in lux value does not experience significant changes. Changes in the lux value that are not too significant are illustrated in Figure 11, a graph about the effect of voltage variations on the lux value of the lamp is tested.

According to the current characteristics that the LED lamp receives from a constant voltage driver, the lux value of the LED light load does not change significantly, as shown in Figure 11. When an LED lamp is used as a load, the current flowing through it has a stable current value, preventing the lamp's lux value from changing even as the voltage from the AC source drops. As a result, when the current flowing in the LED lamp load is constant, the lamp's lux value will also be stable. The lamp's lux value is directly proportional to the current flowing in the load.

Table 4. Data testing the lighting intensity

No	Input Voltage (Volt)	Intense Lighting (Lux)	Average Strong Lighting (Lux)	MAE
1	220	676	681.769	5.769231
2	210	684		2.230769
3	200	683		1.230769
4	190	682		0.230769
5	180	682		0.230769
6	170	682		0.230769
7	160	681		0.769231
8	150	682		0.230769
9	140	681		0.769231
10	130	684		2.230769
11	120	681		0.769231
12	110	680		1.769231
13	100	685		3.230769
		MAE Average		1.514793

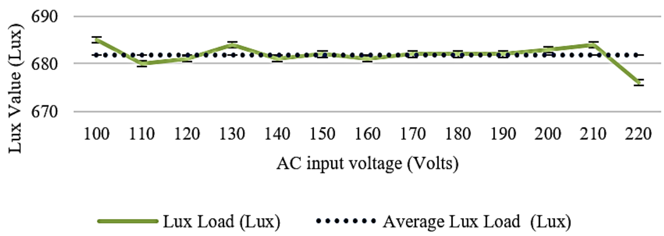


Figure 11. Graph of the effect of input voltage variations on LED lamp lux

4. CONCLUSION

Switch mode power supply (SMPS) LED drivers' flyback topology has produced significant results. First, using a flyback transformer with a switching frequency range of 19–38 KHz, the flyback topology in the SMPS LED driver can convert AC voltage to DC at 18 volts. Secondly, the voltage feedback sent to the IC UC3848AN to control the switching frequency enables the SMPS LED driver to generate a constant voltage with an average value of 18.05 volts. According to the test results, under various input voltage conditions ranging from 100 to 200 Volts, the output voltage value is close to 18 Volts with a 0.3% error percentage. Additionally, this research generates LED drivers with constant current properties at a specific load change. The lights' average lux value, 681.769, is also stable and does not demonstrate any significant changes. These results show how the SMPS LED Driver can create a reliable and effective lighting system for public use.

ACKNOWLEDGEMENTS

The author would like to express our gratitude to the University of Jember for the financial support of this research and for providing us with the necessary resources to carry out this research. Lastly, we would like to acknowledge the contributions of all participants in this study.

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