Voltage Regulation and Power Consumption Analysis of LED Driver using Switched String Method

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Abstract. This paper discusses an AC / DC buck converter-based LED driver to reduce the voltage from 230VAC to 12VDC with a few strings of LEDs. This led driver is designed with a cost-effective circuit because using a single inductor, single inductor multiple-output (SIMO) can reduce the number of components, control the current independently and precisely on each LED string simultaneously, compared to using an inductor on each LED string. To control current and voltage, PWM (Pulse Width Modulation) control is used as a MOSFET signal switch. This MOSFET calculates the duty cycle so that the desired DC output according to the LED specifications can be realized. The circuit was analyzed using PSpice software. The test based on the duty cycle shows that the highest output voltage is obtained with a work cycle of 10% resulting in a voltage of 5.9V and a current of 32.4mA. Meanwhile, achieving the output value based on the led specification with a voltage of 12V and a maximum current of 31mA has been achieved at a duty cycle of 4.7%. This AC / DC buck converter circuit not only lowers the voltage but can overcome dimming and provide a uniform light output on each LED with an output voltage of 12VDC. The experimental results show that this AC / DC buck converter circuit has been tested and can be applied to the Led driver system.

1. Introduction

In recent years, Light Emitting Diode (LED) has increased in various applications, such as in homes, automotive, industrial, and traffic light applications [1], because it has superior quality compared to other light sources such as fluorescent, incandescent, and halogen lamps. [2]. The superior quality is referred to in terms of low power consumption, durability, smooth dimming, these components are also environmentally friendly and produce excellent light [3]. some researchers undertake the development of LEDs by combining drivers to produce more efficient power electronic devices [4].

The rapid growth in LEDs makes the demand for driver circuits increasing. The LED driver circuit is divided into the linear type and switch type. Linear circuits are cost-effective and simpler, but the efficiency depends on the voltage conversion ratio, this circuit is used for low power applications [5-6]. On the other hand, a mode-switch circuit can increase power efficiency. This circuit is used for high power applications. In terms of power efficiency, implementing switch-mode driver circuits has more advantages than linear regulators [7].

The LED driver plays an important role in protecting the LED from current and voltage fluctuations. The change in current in the LED is caused by a change in voltage which causes the light output to vary or decrease rapidly because the temperature inside the LED is higher. To emit a uniform light output, and high accuracy in keeping the current constant over a wide period [8-9], an AC / DC buck converter driver circuit will be designed to reduce the voltage 230VAC to 12VDC with multiple
LED strings using a single inductor multiple-output (SIMO) for component saving and Pulse width Modulation (PWM) technique. PWM was chosen because it provides better dimming flexibility for LEDs compared to other dc dimming techniques [10].

2. Methodology

The buck converter is a converter that functions to convert the AC input voltage into a lower DC output voltage. To get a lower voltage than the input, the buck converter uses a switching component to regulate the performance (duty cycle). The switching component is the MOSFET.

This buck converter circuit is designed to reduce the voltage from 230VAC to 12VDC with several LED strings as the driver application on the LED. Besides, this circuit is also cost-effective because using a single inductor, single inductor multiple-output (SIMO) can reduce the number of components compared to other buck converter circuits that use an inductor on each LED string. In contrast to the circuit that will be designed, a single inductor can control the current independently and precisely, on each LED string simultaneously. Here is a buck converter circuit as shown in figure 1.

![Buck Converter Circuit](image)

The components that make up the buck converter circuit in Figure 1 are in the form of input voltage, a capacitor to filter out the AC ripples that are still present at the diode output so that the resulting DC signal is completely balanced. MOSFET is used to count the current according to the performance (duty cycle) so that the DC output can be as desired. The controller circuit is used to control the MOSFET so that the MOSFET knows when to open and when to close. Inductors are used to store energy in the form of currents. This energy is stored when the MOSFET is turned on and released when the MOSFET is off. Diodes are used to drain the current generated by the inductor when the MOSFET is off. The performance of the buck converter AC / DC is confirmed by the PSpice software with the converter parameters shown in Table I.

| Device max ops | Description       | Value  |
|----------------|-------------------|--------|
| IFD            | Max forward current | 31mA   |
| VD             | Max reverse voltage | 12V    |
| TJ             | Max junction temp  | 100°C  |

| Parameter Converter | Symbol | Value  |
|---------------------|--------|--------|
| Input               | Vac    | 230 VA |
| Input frequency     |        | 50 Hz  |
| Diode Full bridge   |        | 2A, 600V |
Based on the proposed AC / DC buck converter circuit, the value of the 12VDC output voltage can be adjusted by changing the duty cycle value of the semiconductor switch (MOSFET). The MOSFET used in the AC / DC buck converter circuit acts as a switch that can open and close the circuit so that the 31mA current with a 12VDC voltage can be controlled according to the desired duty cycle. The amount of the desired duty cycle value is regulated by the pulse width modulation (PWM) signal [11].

As shown in figure 2:

![Buck converter circuit with PWM](image)

**Figure 2.** Buck converter circuit with PWM

Pulse Width Modulation (PWM) is an effective method for adjusting the buck converter output value. PWM works by creating a square wave that has a high pulse to low pulse ratio which is usually scaled from 0 to 100%. This square wave has a fixed frequency but there are high and low pulse widths in 1 period to be set.

![Pulse Width Modulation graph](image)

**Figure 3.** Pulse Width Modulation graph

In this test, it is carried out based on a varied duty cycle to determine the change in the output voltage generated based on the variation of the duty cycle, so that the value of the output voltage, current, and power can be analyzed based on the response time graph to produce the output voltage and current output according to the LED specifications.

3. **Result and Discussion**

This section presents simulation results based on various duty cycles (10%, 25%, 50%, 75%, and 90%). Based on several tests, the effect of changes in duty cycle on current, voltage, and power is shown in Table 2.
Table 1. Simulation results based on several duty cycles

| Duty Cycle | LED 1       | LED 2       | LED 3       | Voltage | Power    |
|------------|-------------|-------------|-------------|---------|----------|
| 10         | 32.452mA    | 32.452mA    | 32.452mA    | 5.967V  | 213.198mW|
| 25         | 32.821mA    | 32.821mA    | 32.821mA    | 3.638V  | 131.927mW|
| 50         | 32.914mA    | 32.914mA    | 32.914mA    | 2.818V  | 100.182mW|
| 75         | 32.943mA    | 32.943mA    | 32.943mA    | 2.529V  | 88.728mW |
| 90         | 32.959mA    | 32.959mA    | 32.959mA    | 2.429V  | 84.765mW |

The following is a graph of the simulation results of the effect of varying duty cycle changes (10, 25, 50, 75, 90) on the output current on the LED with values (32.452mA, 32.821mA, 32.914mA, 32.943mA, and 32.959mA).

![Figure 4. Simulation results on current](image)

The following is a graph of the simulation results of the effect of varying duty cycle changes (10, 25, 50, 75, 90) on the output voltage on the LED with values (5.967V, 3.638V, 2.818V, 2.529V, and 2.429V).

![Figure 5. Simulation results on voltage](image)

The following is a graph of the simulation results of the effect of varying duty cycle changes (10, 25, 50, 75, 90) on the output power of the LED with values (213.198mW, 131.927mW, 100.182mW, 88.728mW, and 84.765mW).
Based on the simulation results, the effect of changing the duty cycle varies on current and voltage, the average reaches 32 mA and the voltage varies between 2V – 6V. While the circuit whose output is designed must be by the specifications of the LED used in the circuit, namely 12VDC and a maximum current of 31 mA. To find a duty cycle measuring point that affects the current and voltage output based on the LED specifications, the researchers conducted several experiments and succeeded in finding a 31mA current and a 12V voltage that match the LED specifications used in this AC / DC buck converter circuit, namely by using the duty cycle 4.6% and 4.7%, as shown in Table 3 and proven in Figures 7 and 8.

| Duty Cycle | Current (LED 1) | Current (LED 2) | Current (LED 3) | Voltage |
|------------|----------------|----------------|----------------|---------|
| 4.7        | 31.223mA       | 31.223mA       | 31.223mA       | 11.758V |
| 4.6        | 31.120mA       | 31.120mA       | 31.120mA       | 12.224V |

Figure 6. Simulation results on power

Figure 7. Simulation graph of current based on LED specifications
4. Conclusion

This paper presents the simulation results of an AC / DC buck converter circuit with 230VAC input to reduce the voltage to 12VDC. This led driver is also designed with a cost-effective circuit because using a single inductor, single inductor multiple-output (SIMO) can reduce the number of components, compared to using an inductor on each LED string. To adjust the current and voltage, the PWM (Pulse Width Modulation) controller method is used as the MOSFET signal switch. The circuit was analyzed using PSpice software. The results of the experiment were carried out in several stages of the duty cycle response that varied with current, voltage, and power. This variable duty cycle is to obtain the stability of the work circuit if a minimum or maximum switching is given. Based on several duty cycle tests, the highest output voltage is obtained with a work cycle of 10% resulting in a voltage of 5.9V and a current of 32.4mA, while the Led datasheet used shows a voltage value of 12V and a maximum current of 31mA. To get the appropriate current and voltage, the researchers conducted several simulation experiments using the train error method, so that the output matched the LED specifications at a 4.7% work cycle. This AC / DC buck converter circuit not only lowers the voltage from 230VAC to 12VDC but can overcome dimming and provide a uniform light output on the LEDs in each string, even more than three strings of LEDs with one inductor. The part to be achieved is finally fulfilled by recommending tested circuits that can be applied to the led driver system.

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