Direct AC LED Driver for Wide Power Range and Precise Constant Current Regulation

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ABSTRACT

A New Direct AC LED Driver has been proposed for wide output power range and precise constant current regulation using an advanced auto commutation topology. The conventional shunt regulation method provides a stepped input current shape by fixed regulation references in the linear regulator of the each channel, which results in poor current regulation and high THD. The conventional method needs to assign a linear regulator in each LED channel so that the number of linear regulator increases when extending the number of channels especially at high power application. The proposed regulation method can drive multiple switches to regulate each LED channel current by a single amplifier with sinusoidal reference so that large number of LED channel can be simply extended with less BOM cost and low THD is obtained with the accurate current regulation thanks to the sinusoidal input current control in the closed loop control. To confirm the validity of the proposed circuit, theoretical analysis and experimental results from a 20-W LED driver prototype are presented.

1. Introduction

The LED driving systems are being developed as the next generation lighting modules thanks to their excellent lifetime, improved luminance and environmental friendliness [1-2]. These advantages make LED gradually become commonly used in general lighting applications. The brightness of LEDs is proportional to LEDs current so that LED driver generally regulates constant LED current [3]. There are several methods to drive LEDs and the common practice is to use switching-type converters, such as flyback and buck-boost topologies. However, input line filters and electrolytic capacitors are essential in these converters. Therefore, the product size and BOM cost of such LED drivers are usually increased. On the other hand, LED drivers, which can run LEDs directly from AC voltage, have been developed, Direct AC LED Driver [4-6]. These drivers eliminate the line filter and large electrolytic capacitors and driving circuit is composed of multiple channels of LEDs and sequences their conduction according to the input ac voltage level. But, the conventional Direct AC LED drivers suffer from some problem. Since the operation time of each LED string is related to the level of input ac voltage and the current flowing through each LED string is controlled by fixed reference voltage. So, the LED current changes when there is a fluctuation in input ac voltage. Also, the stepped input current shape makes poor THD performance. Moreover, the conventional method needs to assign a linear regulator in each LED channel so that the number of linear regulator increases when extending the number of channels especially at high power application. In order to overcome these disadvantages, a new Direct AC LED Driver has been proposed in this paper. The proposed regulation method can drive multiple switches to regulate each LED channel current by a single amplifier with sinusoidal reference so that large number of LED channel can be simply extended with less Bill of Materials (BOM) cost and low Total Harmonic Distortion (THD) is obtained with the accurate current regulation thanks to the sinusoidal input current control in the closed loop control.

2. Conventional Direct AC LED Driver

As is shown in Fig. 1, the overall system configuration of the conventional Direct AC LED Driver consists of 3 channels LED configuration and there are voltage amplifiers at each channels. Each voltage amplifier has a fixed reference and regulates the LED current of each channel. The basic operation of the conventional circuit is as follow.

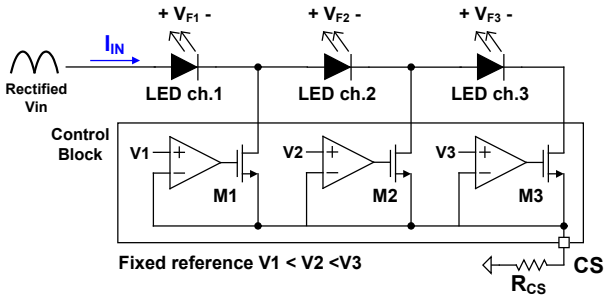


Fig. 1 Conventional Direct AC LED Driver circuit

When rectified input voltage V_{IN} is lower than 1st channel LED forward voltage drop (V_{F1}) there are no current path. So, all LEDs are turned off. Then, V_{IN} is higher than V_{F1}, LED ch.1 is turned on and current is regulated by V_1 of the M_1 amplifier. As the input voltage more increases and becomes higher than $V_{F1} + V_{F2}$, LED ch.1 and ch.2 is turn on. Then the LED current is gradually regulated by V_2 of the M_2 amplifier. Because the voltage reference V_2 is higher than V_1. So, finally M1 is turned off. Same method, when V_{IN} is higher than total LED forward voltage, LED current is determined by V_3 of the M_3 amplifier. Fig. 2 shows the input current waveform according to the operating principle. As mentioned above, the input current is stepped shape by fixed voltage references. In addition, the conventional circuit doesn't know the rectified input voltage information. Thus, input current is not constant according to input voltage range. It means conventional circuit has poor line Constant Current (CC) regulation and THD. Moreover, the conventional circuit requires a voltage amplifier in each channel by extending the number of LED channels for high power application, which complicates the system configuration.

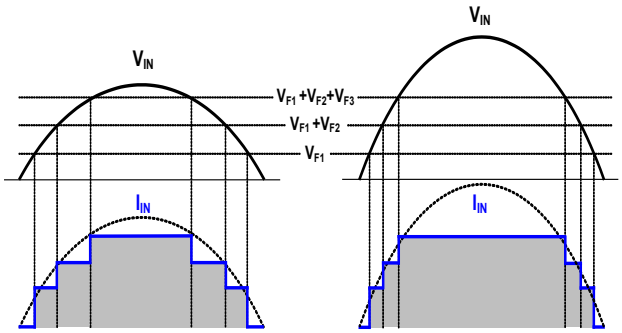


Fig. 2 Input current waveform of conventional circuit

3. Proposed Direct AC LED Driver

In this section, we present the new topology for Direct AC LED Driver and the operation principle of the proposed topology. The general structure of the proposed circuit is depicted in Fig. 3. All switches are controlled by one voltage amplifier and blocking diodes (D_{OUT1}, D_{OUT2}) are connected between previous channel MOSFET source and next channel MOSFET drain. As input voltage increases, the output diodes are turned off one by one in auto commutation of the ambient switches. Therefore, one main amplifier controls all the channel current with one reference. The main amplifier reference $V_{CS(SHA-REF)}$, is sinusoidal so that the input current is optimally sinusoidal with 0.99 PF and less than 10% THD compared to the conventional parallel topology which hardly meets THD in class C due to the stepped input current. How to make the voltage amplifier reference $V_{CS\,(SHA-REF)}$ is described in the next section.

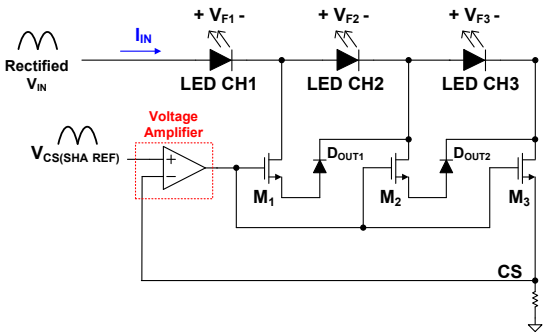


Fig. 3 Proposed Direct AC LED Driver Topology

The state diagram of the proposed circuit according to the input voltage is as follows.

T_0 ($V_{IN} < V_{F1}$): There is no current path. All switches gate voltage is pulled up.

T_1 ($V_{F1} < V_{IN} < V_{F1}+V_{F2}$): switch M_1 regulates LED CH1 current based on $V_{CS\,(SHA-REF)}$ and other switches (M_2, M_3) are fully turned on.

T_2 ($V_{F1}+V_{F2} < V_{IN} < V_{F1}+V_{F2}+V_{F3}$): current starts flowing through M_2 and M1 is gradually turned off by blocking diode (D_{OUT1}) as M_2 Drain voltage is increased. So, it can only one amplifier controls all the channel current with a reference and auto commutation is easily implemented.

T_3 ($V_{IN} > V_{F1}+V_{F2}+V_{F3}$) :By the auto commutation theory, Switch M_2 is slowly turned off by blocking diode D_{OUT2}, and LED current is regulated by M_3.

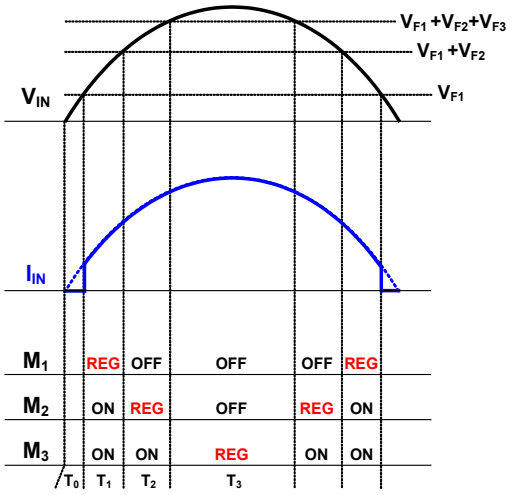


Fig. 4 State diagram of proposed topology according to input voltage

4. Advanced Techniques of Proposed Circuit

4.1 Constant Current Regulation

The LED current is constantly regulated in the closed feedback loop. There are two amplifiers in Fig. 5. The one is to regulate average LED current and another one controls LED current shape. $V_{CS\,(AVG-REF)}$ is target reference for average LED current and OTA compares $V_{CS\,(AVG-REF)}$ and CS voltage to provide FB voltage in average current regulation block. FB voltage makes offset voltage at the reference for current shape regulation.

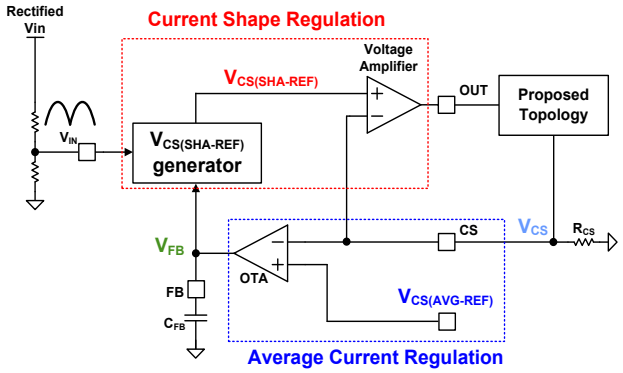


Fig. 5 Current control block of proposed circuit

The LED Current shape reference $V_{CS\,(SHA-REF)}$ is determined by V_{IN} and FB signal. V_{IN} comes from rectified input voltage. As input voltage is increased, FB voltage is reduced to make negative offset. So, V_{IN} makes the sinusoidal shape and FB voltage makes offset to keep the same CS average voltage. Therefore, proposed circuit has excellent line regulation and THD performance than the conventional Direct AC LED driver systems.

4.2 Power Scalability

The advantage of proposed Direct AC LED Driver is power scalability. In high power application using Direct AC LED Driver, channel expansion is essential to disperse the loss of each channel MOSFET. The conventional circuit requires voltage amplifier equal to the number of LED channels, which complicates the circuit configuration. On the other hand, the proposed auto commutation topology can makes it easy to expand the number of LED channels. Therefore, it is possible to drive 300W by expanding the number of LED channels with single voltage amplifier. It is more efficient and simpler to implement than conventional DACD system using multiple voltage amplifiers.

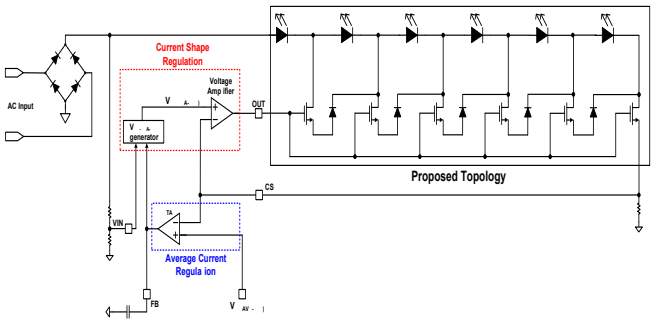


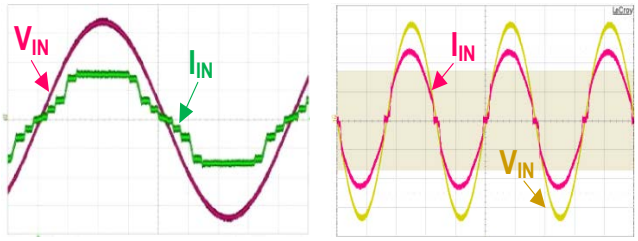
Fig. 6 Power scalability using proposed circuit

5. The Experiment Result

For the verification of the proposed Direct AC LED Driver in this paper, a prototype for 20-W LED driver was produced and the following experimental results are presented. The main parameters for prototype are shown in table 1.

Table 1. System Parameters

Item	Value	Note
Input voltage	108 – 132 V rms	Nominal 120 V rms
Line Frequency	60 Hz	
Power Factor	> 0.9	
THD	< 10%	
Line Regulation	+ / - 1%	+/- 10% input variance
LED specification	6 V / 240 mA	
Number of LEDs	23EA (4-10-9)	3 channel LED strings



a) Conventional circuit b) Proposed circuit

Fig7. System performance comparison

As is shown in Fig. 7, the input current waveform compared with the conventional circuit. As described previous section, since the proposed circuit has a sinusoidal reference, it can be confirmed that the input current shape is also sinusoidal. Therefore, high power factor and low THD performance were verified. In addition, average LED current is precisely regulated by closed control which has less than 1% CC tolerance in mains line variation.

Table 2. Test result for 20W prototype

Input Voltage [V rms]	Input Power [W]	PF	I_{LED_AVG} [mA]	THD [%]
108	18.15	0.99	149.5	7.9
120	20 32	0.99	149.5	6.7
132	22 58	0.99	150.0	7.3

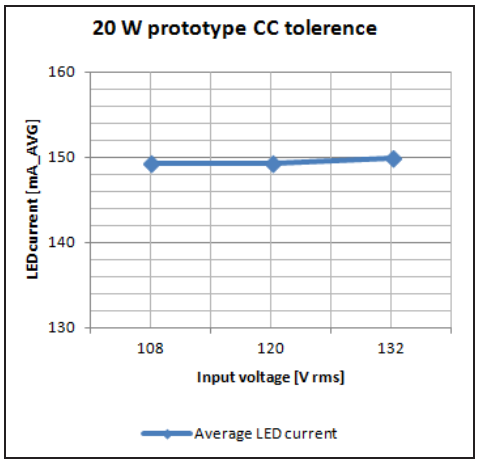


Fig8. Line regulation performance

6. Conclusion

The conventional DACD system is simpler system configuration than the switching mode power supply, but the input current is stepped due to the fixed voltage reference, and there is a deviation of the LED current according to the input voltage by the open loop operation. Therefore, it was difficult to expect low THD and precise LED current control. To solve this problem, a new Direct AC LED Driver has been proposed in this paper. To verify the proposed circuit, a theoretical analysis and a 20W prototype board experiments have been conducted. The proposed circuit is easy to power scalability because one main amplifier can control multiple LED channel switch by auto commutation topology. Also, the LED current is accurately regulated with sinusoidal shape through the average current control block and the current shape control block regardless of input voltage. So, the proposed circuit can obtain CC tolerance less than 1% and excellent THD performance. Therefore, the proposed circuit is suitable for good CC regulation and low THD operation with power scalability in various lighting system.

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