A Single-Stage Electrolytic Capacitor-Less AC-DC LED Driver

Jianguang Ma*, Xueye Wei, Liang Hu and Wenting Jia

School of electronic and information engineering, Beijing Jiaotong University, Beijing, China

*Corresponding author e-mail: 14111042@bjtu.edu.cn

Abstract. The electrolytic capacitor is the mainly component that impact the working lifetime of light-emitting diode (LED). If an ac-dc LED driver with ripple cancellation method, the electrolytic capacitor eliminate is of vital importance. Therefore, this paper present a solution with secondary side full-bridge structure for cancel the twice ac line ripple from the LED driver. In order to reduce the components cost and LED driver volume, a single-stage high efficiency electrolytic capacitor less isolate ac-dc LED driver is implement and discussed in detail, which is a discontinue conduction model (DCM) power factor correction (PFC) buck-boost converter integrated a isolate flyback converter. Finally, a 100W prototype has been built and tested. Experiment results demonstrated the effectiveness and high feasibility of the proposed LED driver.

1. Introduction

Since the invention of the LED, lighting has been mainly used to productivity and commercial occasion. Today, LED lighting is an important aspect of electric power consumption. From 2010, LED lighting has been increase rapidly due to technological improvements have lowered productive costs [1]. Therefore, LED lamps are significantly more preferred green energy-saving environmental protection compare with other lighting devices. For LED lamp will become the central of the lighting field, there is great motivation to developed high efficiency, energy conservation, safety reliable LED driver. The LED driver is responsible for supplies power to the LED lamp. LED is considered as the most energy saving product for lighting, and so it is important that the LED driver should be more high efficiency and energy saving and environmental protection. Hence, LED driver advanced technology development has received a lot of attention in recent years.

The traditional ac-dc LED driver has a two stage circuit for processing input ac line power. This topology is inherently vulnerable to lower efficiency and high component cost. The first stage circuit is utilized a boost circuit for power factor correction (PFC) to achieve a high power factor to comply with relevant harmonic standard regulation, e.g., IEC 61000-3-2 and Energy Star [2]. Usually, the second stage circuit is adapted an electrical isolation dc/dc converter for regulate the constant output current to driver the LED. In order to meet a constant current for driver LED, an electrolytic capacitor with relative large capacitance is responsible for cancellation the difference between input power and out power. However, electrolytic capacitor is not preferred in LED driver, because of it has obvious drawback of short operation lifespan and big volume, compared with LED driver and LED lamp. The lifespan of the electrolytic capacitor is about 5000h in operating environmental, while the estimated
lifespan of the LED is about 50000h, this is a big unmatched lifespan problem [3]. In addition, the
electrolytic capacitor lifespan is closely related to the temperature of the working environment.
Therefore, some studies solution on LED driver without electrolytic capacitor and reduce output
current ripple have been proposed in academic research filed. Generally, the two stage structure
topology, which contains a PFC stage and an isolate dc-dc stage, is more complicated, high system
cost and poor reliability.

![Diagrams](image_url)

**Figure 1.** Tradition high efficiency LED driver configuration. (a) Two-stage schematic diagram. (b) Single-stage schematic diagram.

![Diagrams](image_url)

**Figure 2.** Single-stage electrolytic capacitor-less ac-dc LED driver (a) Schematic diagram. (b) Key waveforms.

In view of the many research paper, the traditional LED driver topology for ac-dc LED driver can
be divided into two categories: two-stage schematic diagram and single-stage schematic diagram as
shown in Fig. 1. The two-stage LED driver topology is shows in Fig. 1 (a), can be realized high power
factor by regulating power transfer twice. The tradition single-stage ac-dc LED driver topology
diagram is shown in Fig. 1 (b), can achieve cost saving, high efficiency and component effective.
Among many single-stage LED driver design solutions, the flyback topology is a very preferred
candidate for dc-dc isolated output constant current regulator. The single-stage ripple cancellation
method makes the flyback LED driver more structure simplicity and cost saving. One method, a bi-
direction ripple cancellation converter is connected with single-stage flyback converter output port to
eliminate the electrolytic capacitor, as shown in Fig. 2 (a). Fig. 2 (b) shows the key waveforms of the
single-stage electrolytic capacitor-less ac-dc LED driver.

To solve these aforementioned draws, in this paper, a single-stage electrolytic capacitor-less ac-dc
LED driver have been proposed, it is integrated the buck-boost circuit and the flyback converter by
sharing the same power switch. Here, the buck-boost circuit used to PFC function of the single-stage LED driver, and the flyback converter is a function of dc-dc constant current regulate, a bidirectional converter serves to absorb the ac component of the pulsating current of the flyback output, leaving only dc component to driver the LED lamps. The proposed ripple cancellation method is commonly applicable to various single-stage ac-dc LED drivers.

![Diagram of the proposed LED driver circuit](image)

**Figure 3.** (a) The single-stage ac-dc LED driver circuit diagram with electrolytic capacitor. (b) Proposed single-stage ac-dc LED driver circuit diagram without electrolytic capacitor.

2. Circuit configuration of the proposed LED driver

Fig. 3 (a) presents the single-stage ac-dc LED driver circuit diagram with electrolytic capacitor, which integrate the buck-boost converter and flyback converter [4]. For the sake of eliminating the short life span electrolytic capacitor, single-stage electrolytic capacitor ac-dc LED driver have been proposed, illustrated in Fig. 3 (b). The buck-boost converter realized the PFC functions to make the input voltage sinuous shape and in phase with the input current. The flyback converter serving as a constant output current regulator, besides it has a galvanic isolation functions. It comprised a floating capacitor full-bridge ripple cancellation converter, which is function as suppress the pulse current. The elimination of lifetime mismatch electrolytic capacitor significantly increases the life span of LED driver to match the life span of the LED lamp. It must notice that the capacitor \( C_O \) in Fig. 3 (b) is a film or ceramic capacitor, which used to filter the high frequency ripple and not storage the energy.

2.1. Basic floating capacitor full-bridge ripple cancellation concept of proposed LED driver

Fig. 2 also illustrates the voltage waveforms of the main circuit output port \( V_{Co} \), folating capacitor full-bridge ripple cancellation converter output port \( V_{Care} \), and the LED voltage \( V_{LED} \). The flyback output voltage, \( v_o(t) \), comprise both ac \( v_{ripple} \) and dc \( V_{dc} \) components, the floating capacitor full-bridge ripple cancellation converter generate a pure ac voltage ripple \(-v_{ripple} \). The output voltage of the flyback can be described as follows:

\[
v_o(t) = V_{dc} + v_{ripple}(t)
\]

Where, \( V_{dc} \) is the dc component of the flyback output voltage, \( v_{ripple}(t) \) is the time-varying ac component of the flyback output voltage. For the sake of reduce the output capacitance, the floating capacitor full-bridge ripple cancellation converter output voltage \( V_{Care}(t) \) is a pure ac. The ripple cancellation output voltage as given in

\[
v_{Care}(t) = -v_{ripple}(t)
\]

The LED lamp voltage is the sum of the single-stage flyback output voltage and the floating capacitor full-bridge ripple cancellation converter output voltage, and it can be described as follows:
\[ V_{LED}(t) = v_a(t) + v_{con}(t) \] (3)

Substitution the equation (1) and (2) into (3) yields the equation (4). At last the LED driver output voltage mainly contains dc component, the eliminating electrolytic capacitor is achieved.

\[ V_{LED}(t) = V_{dc} \] (4)

The capacitance \( C_{aux} \) is very important in design the floating capacitor full-bridge ripple cancellation converter. Therefore, according to the voltage across \( C_{aux} \), the capacitance value is obtain in design the proposed circuit. From the Fig. 2(b), it can be seen that the pk-to-pk value of the voltage in flyback output \( v_{ripple} \) is increasing as the LED output current \( I_{LED} \) increased.

\[ C_{aux} = \frac{I_{LED}}{2\pi \cdot f \cdot V_{ripple}} \] (5)

The input ac line voltage can be described as

\[ v_a(t) = V_a \sin \omega t \] (6)

Where \( V_a \) is the peak value of the input ac line voltage, \( \omega \) is the angular frequency of the input ac line voltage. Here, \( \omega = 2\pi / T_{line} \), \( T_{line} \) is the cycle of the input ac line voltage. \( v_a(t) \) is the instantaneous value of the input line voltage.

When the input current in phase with the input voltage that is the input current is a sinusoidal waveform, the unity power factor is realized, i.e.

\[ i_a(t) = I_a \sin \omega t \] (7)

Where, \( I_a \) is the peak value of the input current, \( i_a(t) \) is the instantaneous value of the input line current.

According to equation (6) and (7), the instantaneous input power can be obtained as

\[ p_a(t) = v_a(t) i_a(t) = \frac{V_a I_a}{2} (1 - \cos 2\omega t) \] (8)

From the above equation (8), the average input power can be obtained:

\[ P_a = \frac{V_a I_a}{2} \] (9)

Assuming that the proposed LED driver is ideal with no loss, means the efficiency is 100%.

\[ P_o = \frac{V_a I_a}{2} \] (10)

Substitution of (9) and (10) into (8) yields

\[ i_a(t) = \frac{p_a(t)}{V_a} = \frac{V_a I_a}{2V_o} (1 - \cos 2\omega t) \] (11)
Where \( i_o(t) \) is the output current of the single-stage flyback converter.

From (11) can be seen that \( i_o(t) \) comprise an ac ripple current component at twice the line frequency. The ac second-harmonic ripple current is:

\[
i_{\text{ripple}}(t) = -\frac{P_o}{V_o} \cos 2\omega t
\]

(12)

For achieve constant current drive the LED lamp, the floating capacitor full-bridge ripple cancellation converter out current should be meet the request:

\[
i_c(t) = -i_{\text{ripple}}(t)
\]

(13)

Where \( i_c(t) \) is the floating capacitor full-bridge ripple cancellation converter out current. Substitution of (12) and (13) into (11) yields

\[
i_{\text{LED}}(t) = i_o(t) + i_c(t) = \frac{P_o}{V_o}
\]

(14)

In view of the equation (14), the LED driving current \( i_{\text{LED}}(t) \) is a pure dc component, meaning that there will be no pulse current.

### 2.2. Single-stage flyback converter

The single-stage flyback integrated buck-boost converter is operated in discontinuous current model (DCM) has been reported and discussed in detail in reference [6]. So, in this paper we will briefly present the operate principle to better understand the proposed LED driver.

Here, suppose the MOSFET switching frequency is much higher than the ac line frequency, therefore the input voltage of the flyback converter can be treated as constant in one period. From the reference [7], when flyback circuit run in DCM, the peak and average current of the transformer primary side in one switching cycle are, respectively

\[
i_{p-pk} = \frac{V_m |\sin \omega t| D_p}{L_p f_s}, \quad i_{p-av} = \frac{1}{2} i_{p-pk} D_p = \frac{V_m |\sin \omega t| D_p^2}{2 L_p f_s}
\]

(15)

\[
i_{s-pk} = n i_{p-pk} = \frac{2 n V_m |\sin \omega t| D_p}{L_p f_s}, \quad i_{s-av} = \frac{1}{2} i_{s-pk} D_p = \frac{V_s^2 D_p^2}{2 V_o L_p f_s} = \frac{V_s^2 D_p^2}{4 V_o L_p f_s} (1 - \cos 2\omega t)
\]

(16)

**Figure 4.** Key waveforms of the primary and secondary current of the flyback converter

### 3. Experimental verification

To verify the effectiveness and feasibility of the proposed single-stage electrolytic capacitor-less ac-dc LED driver, a 100W laboratory prototype is constructed and designed. Fig. 5(a) shows the driving
signal and drain-source voltage waveforms of \( Q_{min} \). Fig. 5(b) illustrates the driving signal voltage waveforms of the ripple cancellation converter switches \( Q_1, Q_2 \). Fig. 5(c) shows the input voltage and input current waveforms of the proposed LED driver. It is obvious that the input current in phase with the input voltage and high power factor is achieved. Fig. 5(d) shows the proposed LED driver implemented photo in the laboratory.

![Image](image_url)

**Figure 5.** Experimental results (a) Driver signal and drain-source waves of \( Q_{min} \)
(b) Driver signal waves of \( Q_1, Q_2 \) (c) Input ac line voltage and current
(d) Photo of experimental in laboratory

4. Conclusion

In order to extend the lifespan and reduce the components of LED driver to match the lifespan of LED lamps and saving the cost, a single-stage high efficiency electrolytic capacitor less isolate ac-dc LED driver is proposed in this paper. The single-stage LED driver integrated buck-boost power factor correction circuit and isolate flyback circuit. Meanwhile, it is removal the electrolytic capacitor through the floating capacitor full-bridge ripple cancellation converter. So the long lifespan film or ceramic capacitor can be implemented in LED driver. The experiment results demonstrated the feasibility of the proposed ac-dc LED driver design method.

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