Flyback based three-port electroless capacitor LED drive power

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Abstract: **LEDs are widely used in all walks of life due to their good performance. But its core part, the driving power, is the key to ensuring long-term stable and efficient operation of the lighting system. Therefore, solving the defects of electrolytic capacitors in LED driving power and extending the working life of LED driving power is of great significance to the development and popularization of LED lighting systems. This article uses a transformer-isolated Fly-back PFC circuit and a small-capacity CBB capacitor to balance the input power. Combining dual-input and dual-output converters, a three-port converter is constructed, and three power transmission paths are realized through power transmission between three ports. When the input power is greater than the output power, the energy storage capacitor stores excess energy; conversely, the energy storage capacitor releases energy to the load circuit to balance the input power and output power. Among them, the DC / DC converter implements the PFC function, and the energy storage capacitor performs power transmission through charging and discharging, balancing the pulsating power between the input power and the output power to achieve a constant power output, thereby reducing the ripple current and achieving a flicker-free purpose.**

Keywords: **AC/DC drive power, Fly-back converter, Buck circuit, three-port converter.**

1. INTRODUCTION

In recent years, people around the world have paid close attention to issues such as energy shortages and environmental pollution. Energy saving and emission reduction have become an important promotion. Lighting is an important aspect of human energy consumption. How to improve the efficiency of electric light sources effectively is of great significance in alleviating energy and environmental problems.[1] LED will gradually replace traditional light sources in the next ten years and become the new light source with the most development potential due to its excellent characteristics of environmental protection, high efficiency and energy saving.[2] However, the life of electrolytic capacitors in the traditional AC/DC LED drive power supply on the market is short, which severely limits the life of LED lamps.

According to research, electrolytic capacitor failure is the most common in the failure of LED driving power. The heating effect of the light bulb causes the temperature in the driving device to be relatively high, which accelerates the volatilization of the medium inside the electrolytic capacitor, thereby reducing the life of the electrolytic capacitor. The short-lived electrolytic capacitors cause waste of LED lighting systems and increase in manufacturing costs. Therefore, solving the defects of electrolytic capacitors in LED driving power and increasing the stable working time of LED driving power are of great significance to the development and popularization of LED lighting systems.[3]

2. PROPOSED METHOD

2.1 Design ideas

Optimizing the topology is mainly to select the appropriate auxiliary network for organic integration according to different PFC converters. The methods to achieve energy balance include: parallel auxiliary network topology, using integrated auxiliary network topology, adding energy storage elements such as inductors and small capacitors, etc. [6]. For example, an additional auxiliary energy storage element is used to reduce the power pulsation difference ΔE. When the input power is greater than the output power, the excess energy is stored in the energy storage inductor. When the input power is less than the output power, the energy stored in the energy storage inductor is transferred to the output to fill the part where the input is less than the output. However, due to its large magnetic loss and winding loss, and its volume is large, and the capacitor is generally non-destructive, energy storage capacitors are generally used as energy storage elements. The basic block diagram of this electroless capacitor LED drive power is shown in the figure Show.

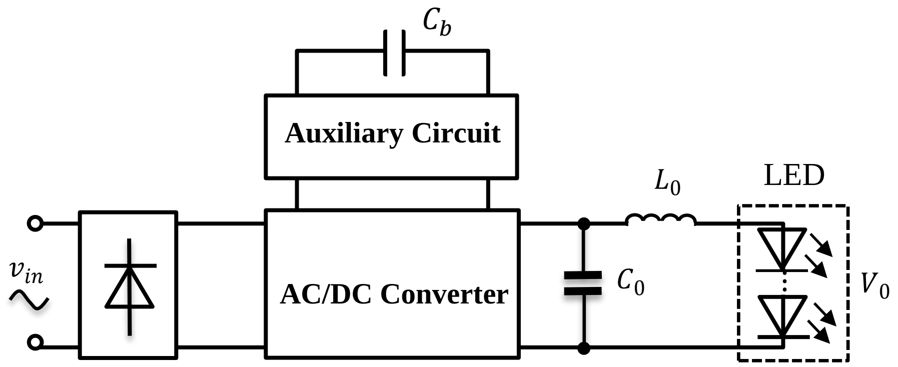


Figure 1: Auxiliary Energy Storage Circuit Eliminates Electrolytic Capacitors

The output inductor Lo and the output capacitor Co constitute a low-pass filter, which is used to filter out the high-frequency components in the current. Therefore, the output capacitor capacitance is very small. Film capacitors or ceramic capacitors can be used instead of electrolytic capacitors. Increasing the voltage ripple value and the average value of the voltage on the energy storage capacitor can significantly reduce the capacitance value, so that film capacitors or ceramic capacitors can be used instead of electrolytic capacitors as energy storage capacitors, but the performance of LED drive power needs to be guaranteed through improvement.

2.2 Research objectives

The electrolytic power of the LED driving power on the market is easy to break, short in life, and difficult to replace the driving power, which greatly reduces the life of the LED. If other circuits are used to replace the filtering function of electrolytic capacitors, there will also be shortcomings such as flicker, low power, and poor stability. Therefore, the research goal of LED drive power without electrolytic capacitors is not only to improve the service life of LED lamps, but also to ensure that the drive power has good performance and stable operation.

AC / DC LED Drive Power Without Electrolytic Capacitor	
Long Life	Removal of electrolytic capacitors through circuit modification of the secondary side of the high-frequency transformer of the Fly-back Converter, thereby extending the life of the LED drive power.
No Strobe	The secondary side of the high-frequency transformer was modified. Reducing the power ripple difference ΔE effectively using energy storage effect of the inductor
High Power	The input current and input voltage have similar waveforms.

Figure 2: Purpose of Scheme Design

3. KEY TECHNICAL ISSUES

Without changing the output power, input voltage angular frequency, and average voltage of the storage capacitor, the ripple voltage at both ends can only be reduced by increasing the capacitance of the storage capacitor. Generally, in the LED AC / DC driving voltage, electrolytic capacitors with larger capacitance values are used as energy storage elements. Other types of capacitors have smaller capacitance values. However, due to the influence of the life of the electrolytic capacitor on the life of the LED driving circuit, the need for the energy storage capacitor capacity can only be reduced by optimizing the topology circuit structure.

3.1 Optimize the topology circuit

The pulsating input voltage can be viewed as the superposition of a constant DC voltage and a ripple voltage. To make the output power constant, an energy storage capacitor is required to process the ripple component. The function of the energy storage capacitor C_b lies in energy storage, so as to achieve the role of charge and discharge balance input and output power.[5]

In a two-input circuit, a storage capacitor storage circuit in a topology circuit. When the input power is less than the output power, energy can be provided by the energy storage capacitor. The second-order low-pass filter composed of the smaller CBB capacitor C_0 and inductor L_0 is used to filter the switching frequency and its multiple frequency components in the output current of the PFC converter, thereby preventing high-frequency harmonic current from flowing into the LED. [9] In addition to the DC component, the output current of the PFC converter has a double power frequency AC component. In order to remove this double power frequency component, a DC / DC bidirectional converter is connected in parallel to the output of the PFC converter, and its input current is controlled to be equal to the double power frequency AC component, so that the current input to the LED load is a straight DC current. Then achieve the purpose of eliminating LED flicker.

According to the instantaneous current p_{in} expression, the current $i_0'(t)$ can be calculated:

$$i_0'(t) = \frac{V_m I_m}{2V_0}\left(1-\cos 2\omega t\right) = I_0\left(1-\cos 2\omega t\right) \tag{1}$$

It can be known that the average current of the LED driving power supply:

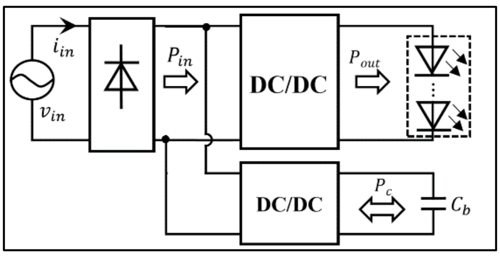
$$I_0 = \frac{V_m I_m}{2V_0} \tag{2}$$

It can be known from equation (2) that i_0' contains a DC component and an AC component with twice the power frequency. The DC / DC bidirectional converter connected in parallel to the output of the PFC converter is controlled so that its input current i_b is equal to the AC in i_0'' Weight:

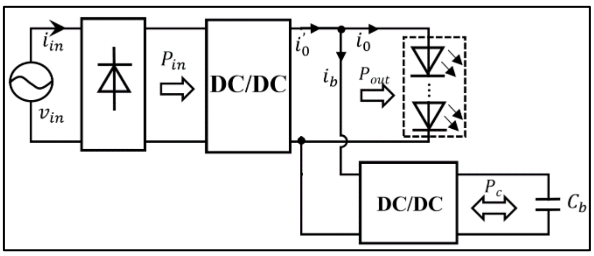
$$i_b(t) = -I_0 \cos 2\omega t \tag{3}$$

The output current i_0 contains only a DC component, which can eliminate the flicker phenomenon of the LED. Similarly, in a dual output conversion circuit, when the input power is greater than a constant output power, the excess energy is transferred to an energy storage capacitor for storage. A three-terminal converter is constructed based on the traditional DC / DC converter. The first is to increase the power transmission path. The transmission paths are power input to LED load, power input to energy storage capacitor, and energy storage capacitor to LED load. The second is to increase the power flow control variable, control the power transmission between the three ports, and balance the pulsation between input and output power. [10] The above-mentioned dual-input converter and dual-output converter are combined into a combined topology circuit, a dual-input dual-output conversion circuit, as shown in the figure below. The DC/DC converter implements the PFC function, and the energy storage capacitor performs power transmission through charging and discharging, thereby balancing the pulsating power between the input power and the output power to achieve a constant power output.

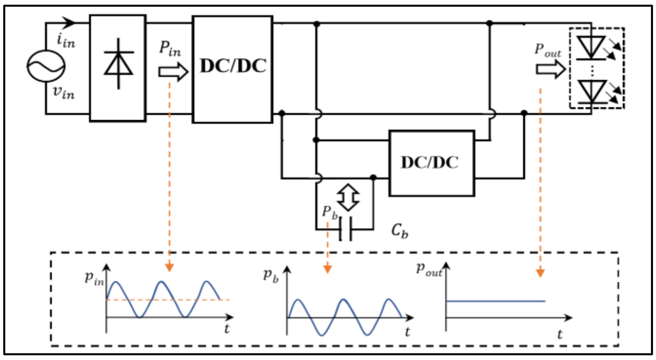
The above two-input-dual-output conversion circuit is integrated and optimized, and simplified into a three-port converter.



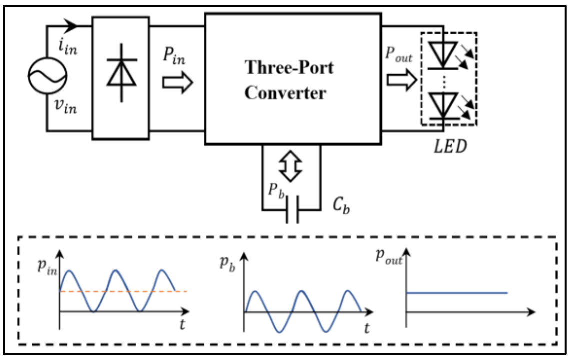
a. Dual input conversion circuit



b. Dual output conversion circuit



c. Dual input-dual output conversion circuit



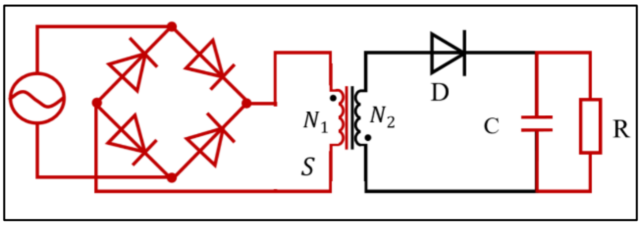
d. Three-port converter

Figure 3: Three-port circuit conversion principle

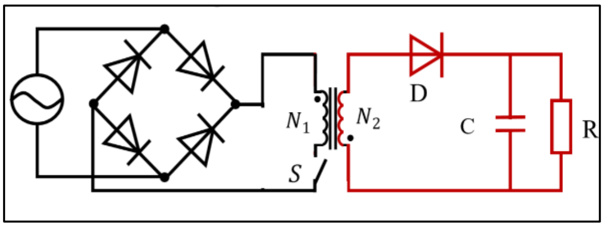
3.2 Topology Design Principle

A. Flyback converter working principle

A flyback converter is a type of switching power supply that provides insulation between the input and output stages. The core components include switches, transformers, diodes, and capacitors. The switch is controlled by pulse width modulation (PWM), and by closing and conducting, a high-frequency square wave signal is generated at both ends of the transformer. [11] The transformer transmits the generated square wave signal to the secondary coil in a magnetic field-induced manner. Then through the filter and rectification of the diode and capacitor, a stable DC output can be obtained at the output end. The working principle of the flyback converter is shown in the figure below.



a. Switch closed



b. Switch off

Figure 4: Flyback converter circuit works

When the switch is closed, the primary coil of the transformer is connected to the input voltage, the current in the primary coil and the magnetic field in the transformer core increase, and energy is stored in the core. However, the voltage generated in the secondary coil of the transformer of the opposite end is reversed, the diode is in a reverse biased state and cannot be turned on, and the capacitor provides voltage and current to the load.[7] When the switch is turned off, the current in the primary coil is zero, the magnetic field in the core decreases, and a forward voltage is induced on the secondary coil. At this time, the diode is in the forward direction, the current flows into the capacitor and the load, and the energy stored in the magnetic core is charged into the capacitor and the load.

B. Buck converter circuit works

The equivalent circuit model of the buck converter circuit is shown in the figure below. Among them, the inductor L and the capacitor C form a low-pass filter, which can pass the DC component in the power supply and suppress the harmonic component, so the output voltage on the capacitor is the DC component of the power supply voltage, with a small ripple component added. Due to the high operating frequency of the circuit, the ripple voltage caused by capacitor charging and discharging during a switching cycle is very small, much smaller than the DC voltage of the capacitor output, so the ripple voltage can be ignored, and the output voltage of the capacitor can be regarded as Constant DC.

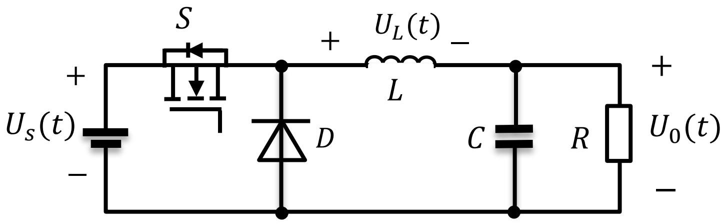
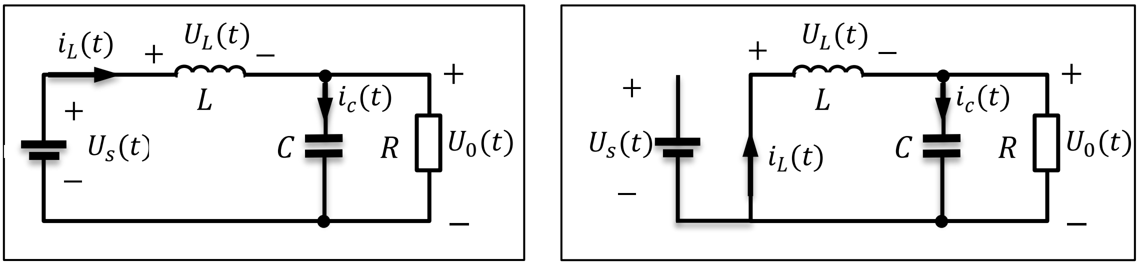


Figure 5: Buck circuit structure

When the switch S is turned on, the inductor current increases and the energy is stored in the inductor. The equivalent circuit is shown in the circuit on the left side of the figure below. When the switch S is turned off, the inductor current decreases and the inductor releases energy.



a. Switch-on equivalent circuit **b. Switch-off equivalent circuit**

Figure 6: Buck circuit working principle

3.3 Main circuit topology

The main circuit is a three-port converter based on the Fly-back circuit and Buck circuit. The circuit is shown in the figure below. Among them, the diodes D1 and D2 on the right side of the secondary coil constitute a dual output circuit, which increases the power transmission path from the input power to the energy storage capacitor. [4]The Buck converter composed of the switch S3, the diode D3, the inductor L, and the load constructs a power transmission path from the storage capacitor to the output power.

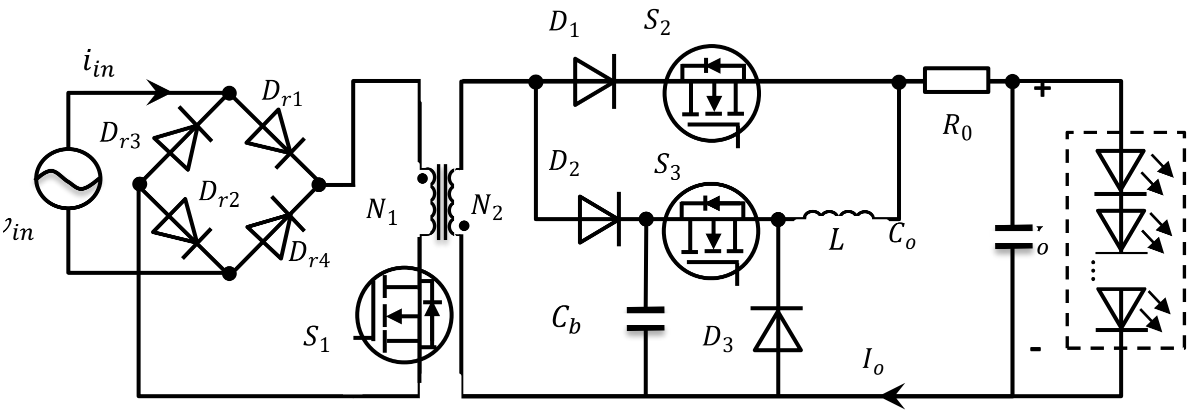


Figure 7: Main Circuit Topology

The calculated input power P_{in} and output power P_{out} are as follows:

$$\begin{cases} p_{in} = \frac{1}{2} V_m I_m \cdot (1 - \cos 2\omega t) \\ p_{out} = \frac{1}{2} \cdot V_m I_m \end{cases} \tag{4}$$

It can be known from the above formula that the input power is a cosine function that increases the output power. To make the load circuit work in a stable working environment, it is necessary to reduce the difference between the input and output power through a control strategy.[13] The switch S1 in the circuit is used to control the average voltage of the energy storage capacitor C_b, so that the Fly-back converter works in the current discontinuous mode to realize the PFC function.[8] When the main circuit works stably, the average voltage of the energy storage capacitor is constant, and the duty ratio of the switch S1 is basically unchanged.

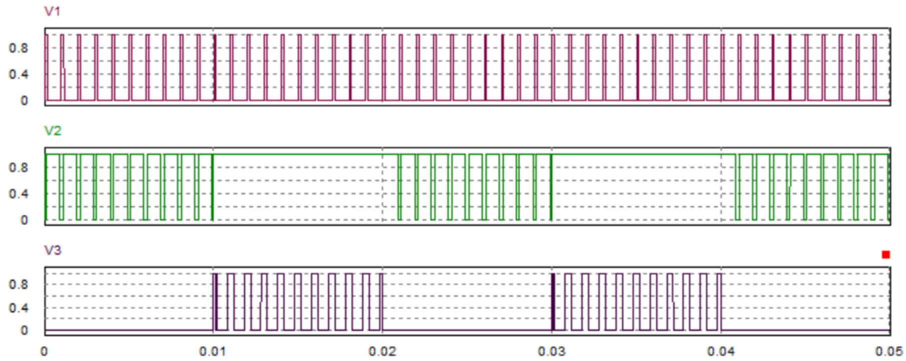


Figure 8: The Waveforms of MOS Tubes Sequential Circuit

In the above figure, V1, V2, and V3 are the gate-level input signals of the switches S1, S2, and S3, respectively. Among them, V1 is a rectangular wave that provides gate-level signals for the high-frequency switching power MOS tube, and V2 and V3 are SPWM waves. The MOS tubes S2 and S3 work alternately. When the input power P_{in} is greater than the output power P_{in}, the excess energy is charged to the storage capacitor C_b, the voltage of the storage capacitor rises, the switch S3 is in a constant off state, and the switch S2 is controlled to provide a constant current to the load; when the input power When P_{in} is less than the output power P_{out}, the energy storage capacitor provides the missing energy to the load, and its voltage drops. Switch S2 is in a constant on state, and control switch S3 provides a constant current to the load.

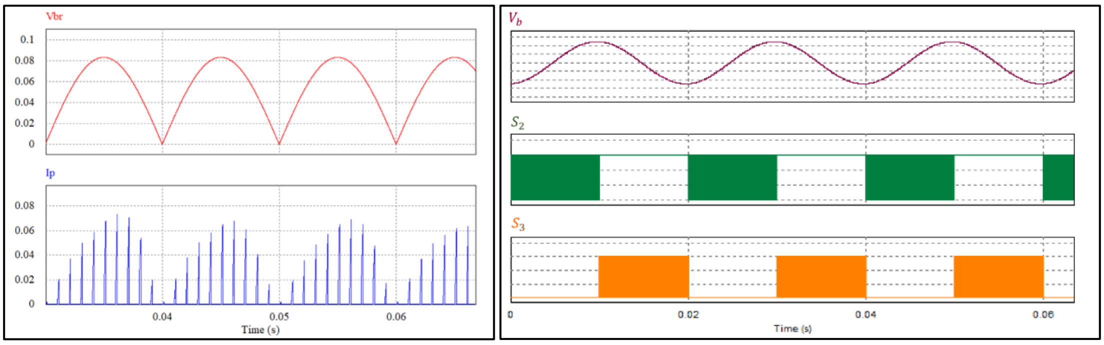
4. SIMULATION EXPERIMENT RESULTS

After analyzing the principle of the transformer-isolated Fly-back PFC circuit and detailed calculations, a high-power factor, flicker-free, long-life LED drive power supply was designed and experimentally verified. When the input voltage is 150 ~ 260V AC / 50Hz, the full load output current is 0.8A, the output power is 28.8W, and the efficiency is higher than 0.9, the specific indicators are shown in the following table:

TABLE I: Experimental parameters

Index	Parameter
Transformer turns ratio (N_1:N_2)	2:1
Input AC voltage (V_{in})	150~260V AC/50Hz
Rated output voltage (V_0)	36V DC
Full load output current (I_0)	800mA
Full load output power (P_0)	28.8W
Effectiveness (μ)	Greater than 90%

Based on the main parameters given in the table above, the simulation analysis uses PSIM simulation software to verify the combined three-port topology circuit. Take the waveform diagram of the rectifier bridge output V_{br} and the transformer primary output current I_p during stable operation, as shown in the figure below.[14] It can be seen from the simulation diagram that the switching cycle of the primary current of the transformer is consistent with the fundamental wave of the primary current, and the periodic current can automatically track the full-wave rectified voltage, realizing the function of the main circuit.

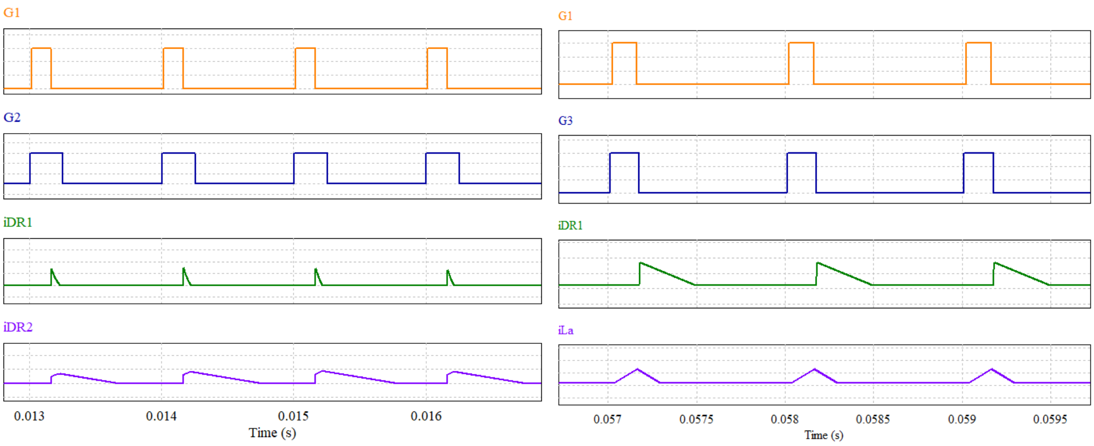


a. Rectifier bridge input voltage and primary side input current of Fly-back Converter

b. Voltage Waveforms of Energy Storage Capacitors and Working Waveforms of Switches S2 and S3

Figure 9: Simulation waveform

The figure above shows the voltage V_b of the energy storage capacitor C_b and the driving waveforms of the switches S2 and S3. When S3 is in a constant off state, $C_b$is in a charging state and V_b rises, and S2 provides constant power for the LED; S2 is in a constant on state, C_b releases energy, and V_b drops. At this time, control S3 to provide constant power.



a. Input power greater than output power **b. Input power less than output power**

Figure 10: Simulation waveform

Figure 10.a shows the waveforms of G1 and G2 and the current waveforms of D1 and D2 diodes when the input power is greater than the output power. From the simulation results, it can be concluded that when the circuit works under this power condition, S1 and S2 are on, the transformer stores energy, and D1 has no current flowing during this period; after S1 is off, S2 is still in a normal on state. During a conducting period, the transformer releases energy. After a certain period of time, S2 is turned off, and the remaining energy stored in the transformer is transmitted to the energy storage capacitor through D2. The transformer is in a process of intermittent energy storage and energy release, and the simulation is consistent with the theory described above.

Figure 10.b shows the waveforms of G1, G3 and D1 diode a inductor current when the input power is less than the output power. From the results obtained from the simulation, it can be known that when S1 is turned off, the transformer works in a discontinuous state, at which time the input power provides energy to a certain low level, so that the current flowing through the diode is small. At the same time, the energy storage capacitor releases energy through S3 control to ensure the total output. The simulation is consistent with the previous theory.

The final simulation output results are shown in the following figure. The following voltage output waveform diagram is obtained through the PSIM simulation software. The resulting voltage waveform is in a stable state, eliminating severe flicker.

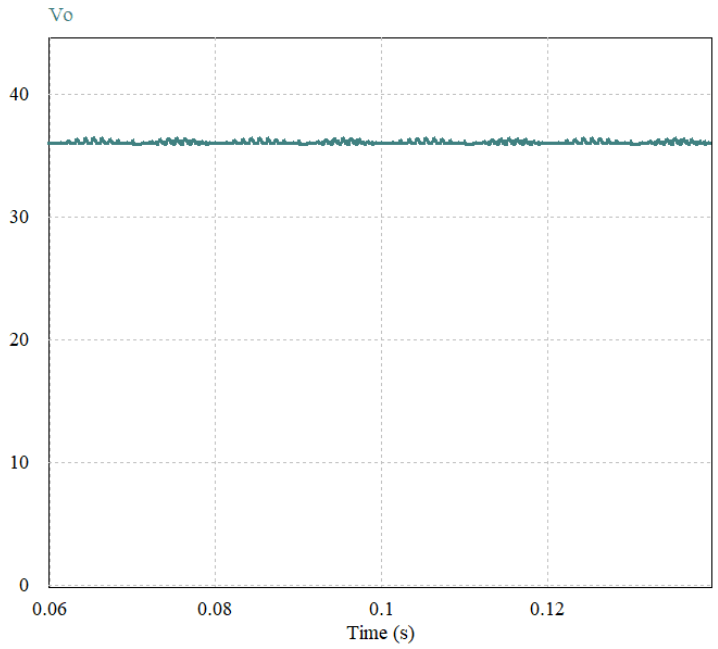


Figure 11: Output Voltage Waveform When the Main Circuit is Stable

5. SUMMARY

This article discusses the design scheme of AC / DC LED driving circuit without electrolytic capacitor based on LED driving power. The main research work and summary are as follows: Using the method of optimizing the topology, a design scheme of no electrolytic capacitor, no flicker and high-power factor is proposed. Design a three-port converter to balance input power and output power, and eliminate the severe strobe phenomenon caused by pulsating input power. This article describes the basic working principle of the Fly-back and Buck circuits and the working principle of the control circuit, and analyzes the simulation results of the PSIM simulation software. The resulting 36V voltage waveform is stable, eliminating severe flicker. Due to the limited time and level, the research in this paper is not thorough and comprehensive, and the theoretical level and practical application need to be improved.

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