Design of a flyback high-efficiency switching power supply

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Abstract. Switching power supplies are widely used in automotive, aviation, and DC speed control fields. Its biggest requirement is stable output and high efficiency. It is usually realized by resonant converters, but its control circuit is complex and the output ripple is large. In this paper, a new type of flyback switching power supply is designed using a flyback conversion circuit and a single-tube self-excited conversion circuit. Experiments have shown that the designed switching power supply improves the efficiency and reliability of the power supply while obtaining a small ripple, continuously adjustable, and stable DC voltage.

1. Introduction

With the development of production and technology, the requirements for environmental protection and energy have become higher and higher, and the application of switching power supplies has become more and more extensive. There are many types of switching power supply circuit structures, including single-ended converters and double-ended converters. This article introduces a design method that uses a flyback conversion circuit to implement a 5V switching power supply, which improves the efficiency of the power supply system and can be used as a mobile phone charging power supply [1].

2. Design index requirements

We have made the switching power supply as shown in Figure 1
Under the condition of resistance load, the designed switching power supply meets the following requirements.

① AC voltage $U_1$ is: 180V~240V.
② DC voltage $U_0$ is: 4.5V~5.5V.
③ Output current $I_{OMAX}$: 2A.
④ Load regulation $S_I \leq 10\%$.
⑤ DC/DC converter $\eta \geq 90\%$ ($U_0=5V$, $I_0=1A$).

3. Module circuit design

3.1. Rectifier filter circuit design
According to different rectification methods, the rectification circuit can be divided into full-wave rectification and half-wave rectification. In order to improve working efficiency, the rectifier circuit generally adopts a bridge rectifier circuit. Considering that the output power of the circuit is not very large, if a three-phase bridge rectifier circuit is used, it will increase the complexity of the circuit and increase the loss, so this system uses a single-phase bridge rectifier circuit. A bridge rectifier circuit or rectifier bridge composed of four diodes can be selected. The diode used is a more general 1N4007, which has good stability and can meet the requirement of low current. RS310 is recommended for the rectifier bridge. The rectified unipolar voltage fluctuates greatly and is not smooth enough. It is necessary to use a filter circuit to filter out the AC component, so that the unipolar voltage with large fluctuations becomes a relatively smooth DC voltage. The filter circuit is generally composed of capacitors, inductors and resistors. In addition to resistors, capacitors and inductors can be used alone. For low-power power supplies, capacitor filtering is generally used.

3.2. DC/DC topology circuit scheme
According to design requirements, the DC/DC converter should have a step-down function, and there are many circuit structures that meet the requirements [2-3]. There are mainly two types of single-ended converters (flyback, forward) and double-ended converters (push-pull, half-bridge, and full-bridge). This project uses a single-ended flyback converter, because the flyback circuit uses the fewest components. Experience has shown that when the power level is lower, the total power supply device cost will be lower than other circuit technologies. A simplified schematic diagram of the working principle of a single-ended flyback converter is shown in Figure 2.
Figure 2. Working principle of single-ended flyback converter and diagram of the primary and secondary current waveforms.

When the excitation pulse applied to the primary side main power switch tube VT is high, VT is turned on, and the DC input voltage E is applied to both ends of the primary side winding NP. The phase of the secondary winding is upper negative and lower positive, so that the rectifier VD is reversely biased and ends. When the driving pulse is low to make the switching tube VT cut off, the polarity of the voltage across the primary winding NP is reversed, and the rectifier tube is forward biased and turned on. After that, the magnetic energy stored in the transformer is transferred and released to the load. Therefore, the single-ended flyback converter is a kind of "inductive energy storage converter".

When the single-ended flyback converter works in the discontinuous state of magnetizing current, the calculation formula of the output voltage is as formula (1).

$$V_0 = E \cdot I_{on} \cdot \frac{R_L}{2L_{p}T}$$  \hspace{1cm} (1)

In the formula, $I_{on}$ is the conduction time of the switch, $T$ is the conduction period, and $L_p$ is the equivalent inductance of the primary winding.

When the single-ended flyback converter works under the continuous state of magnetizing current, the output voltage is calculated as formula (2).

$$V_0 = E \cdot \frac{N_S}{N_P} \cdot \frac{D}{1 - D}$$  \hspace{1cm} (2)

In the formula, the duty cycle $D = \frac{I_{on}}{T}$.

It can be seen from the above formula that the single-ended flyback circuit can stabilize the output voltage when the grid voltage changes or the load changes. Most single-ended flyback converters work in a continuous state of magnetizing current [3].

During the cut-off period of the switch tube VT, the voltage it bears is as formula (3).

$$V_{CE} = E + V_{LP} = E + \frac{N_P}{N_S} V_0$$  \hspace{1cm} (3)

When selecting a switching transistor, not only the maximum value of the primary current of the transformer not exceed the limit value of the transistor, but also the voltage amplitude of the transistor must not exceed the allowable value of the transistor. Especially in the open circuit test, the load should not be disconnected to cause the output voltage to increase sharply and damage the power tube.

3.3. Power switch tube drive circuit

The switching tube drive circuit is the most critical part of the switching converter. Switching power converters can be divided into self-excited conversion circuits and separately excited conversion circuits according to different excitation methods.

The system uses the self-excited conversion circuit shown in Figure 3. It is a self-excited inverter circuit that uses transformer coupling to form positive feedback.
Figure 3. Single transistor self-excited conversion circuit.

In this circuit, T is the switching transformer, $L_f$ is the feedback winding, and $R_1$ provides the initial starting current for the base of the switching tube VT, also known as the starting winding. C is a coupling capacitor, and $R_2$ provides a discharge path for capacitor C.

The transformer design method of the single-ended flyback switching power supply is quite different from other types of converters. Its design parameters mainly include the following two items.

3.3.1 Primary winding inductance $L_P$

From formula (1), we can get as formula (4).

$$L_p = \frac{t^2 m E^2 R_L}{2V^2 \eta T} \quad (4)$$

3.3.2 High frequency transformer core

The power of a flyback converter is usually small, and a ferrite core is generally used as the transformer, which is determined according to formula (5).

$$A_p = A_e A_\varnothing = \frac{P_1 10^6}{2\eta f_s B_m \delta m K_C} \quad (5)$$

In the formula, $A_e$ is the cross-sectional area of the core ($cm^2$), and $A_\varnothing$ is the cross-sectional area of the core window ($cm^2$). $P_1$ is the nominal output power of the transformer (W). $B_m$ is the cross-sectional area of the magnetic induction intensity of the core working (G). $\delta$ is the current density of the coil wire, usually $\delta = 2 \sim 3 \ (A/mm^2)$. $\eta$ is the transformer efficiency. $K_m$ is the fill factor of the window. $K_C$ is the filling factor of the magnetic core. $f_s$ is the frequency of the switching tube [4-6]. According to the calculated value $A_p$, select a core with a larger margin. Each magnetic core has a fixed area. In the magnetic core parameter table provided by the manufacturer, query the magnetic core greater than or equal to the required area to obtain a magnetic core that meets the requirements.

4. System design

The overall design of the system is shown in Figure 4.
Figure 4. Switching power supply system circuit diagram.

The switching power supply test waveform is shown in Figure 5.

Figure 5. Output waveform when the load is 5Ω.

5. In conclusion
Compared with the traditional converter, the switch tube drive circuit adopts a single-tube self-excited conversion circuit, the control circuit is simple, the switch tube voltage stress is smaller, and the efficiency is higher. Experiments show that the power supply has a low voltage regulation rate, good output waveform, reliable work, and can be used in small and medium power supply occasions.

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