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Transformer Selection Calculation for the design of Flyback Switching Power Supply

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Abstract. Pulse-width modulating (PWM) is one of the most popular methods to design the switching power supply. The framework to design a novel flyback switching power supply with a PWM integrated circuit is described in this paper. In order to meet the design demand, the significant step of transformer selection calculation is discussed in details. A_P method is used in the transformer calculation. Then some other parameters of the transformer, such as the transformer ratio, Primary current of transformer, the primary inductance of transformer, the transformer turn and air gap and the wire diameter of the winding, are computed step by step. With the selected transformer, the proposed switching power supply has simpler circuit and higher accuracy. Different input voltage ranges and output voltages required by different electric appliances can be well satisfied.

1. Introduction

In the design progress of switching power supply, efficiency is one of the most important indicators. So far the efficiency of domestic switching power supply is mostly about 70%. In order to respond to the call of energy saving and emission reduction in China, the design concept of future switching power supply should be focused on reducing the loss and improving efficiency while designing. The loss of switching power supply is composed of input rectifier loss, switching loss, loss of buffer circuit, conduction loss, loss of transformer and inductance, etc. Besides the loss of input rectifier, other losses can all be reduced. These years the relatively new technology is to adopt zero voltage/zero current switching synchronous rectifier to reduce the switching loss and grid drive loss of synchronous rectifier^[1-2]. In the future, period-hopping control could be used to reduce light load and standby loss. There are many ways to improve efficiency, such as passive lossless snubber circuit, synchronous rectifier, low power control chip and so on. Flyback topology is proved to be an effective solution for making switching power supply due to its low cost and high efficiency^[3]. For example, the AC-DC adapters and chargers of laptops are realized by pulse-width modulating (PWM) power conversion. Therefore, in order to improve the efficiency and reduce the loss, a novel flyback switching power supply for the electronic devices with low power is proposed in this paper.

The rest of this paper is organized as follows. First, the working principles will be proposed in Section 2. Second, the design indicators and the system framework will be described in Section 3. In this



section, the hardware framework and the function of the modules will be proposed. Furthermore, the calculation to select transformers will be introduced in Section 4, as well as some other parameters of the transformer. Then the conclusion will be stated in the last Section.

2. Working principles

To adapt to different output power, switching power supply has a variety of topologies: Boost, Buck, Flyback, forward, half bridge, full bridge and so on^[4-5]. In this design, the major indices are as follows: the output voltage and current, power and switching frequency are 12V, 3.4A, 40W and 65 KHz respectively. Hence the flyback topology is chosen in this paper to meet the specification of simple circuit and power level. The so-called flyback repeats that the primary side polarity of transformer is opposite to the secondary side polarity. When the switch is on, the energy is stored in the transformer, and when the switch is off, the output rectifier diode is turned on, providing energy to the output capacitor and load. At the same time, flyback switching power supply can output multiple sets of voltages which can be isolated from each other. As a good choice for the switching power supply less than 100W, they provide power to the chip and energy to the output simultaneously. If the upper end of the primary side of the transformer is positive, the upper end of the secondary side is negative^[6]. Flyback converter is widely used because of its high efficiency, simple circuit and multichannel output. Unfortunately, the ripple voltage is relatively high. We can use larger output filter capacitor and inductance to solve this problem. But this will make the power supply larger.

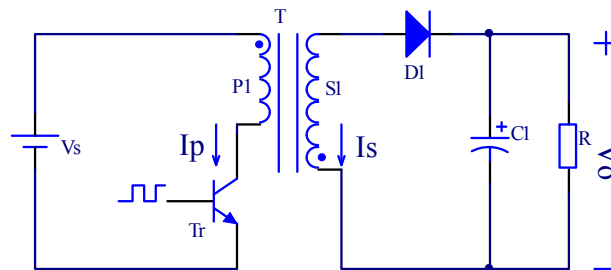


Figure 1. Flyback converting circuit

Recently, developers have found that small LC noise filters is effective. Flyback converter has two working mode. One is complete energy conversion. All the energy stored in the storage cycle of the transformer is transmitted in the flyback cycle. The other is incomplete energy conversion. Some of the energy stored in the transformer during the energy storage cycle is kept in the flyback cycle until the next energy storage cycle. While using complete energy conversion mode in PWM switching converter, the width of the starting pulse of the control circuit can be reduced. But there are some problems such as waveform distortion and modulation difficulties^[7-8]. Only the incomplete energy conversion method is discussed here.

The flyback converting circuit is described in Figure.1. When the switch transistor Tr is off, the energy accumulated on the primary side of the transformer is transferred to the secondary side. At this time, the lower end of the secondary winding is negative while the upper end is positive. The diode D1 is positive conduction. The conduction voltage is filtered by the capacitor C1 to supply power to the load R. When the stored energy on the primary side of the transformer is released to a certain extent, the power supply voltage charges the collector of the transistor through the primary winding of the transformer. The primary winding begins to store energy. When V_s rises to a certain extent, the transistor is off and a new round of discharge begins. During the charging cycle, the output voltage of the converter is $V_o = \frac{N_2}{N_1} * V_s * D$.

3. System design framework

In order to make the power supply work stably in practical applications, it is often necessary to set high voltage protection, conduction interference suppression, green energy saving and other functions.

So switching power supply should have some important indicators. For example, the Input voltage range should be 100-240Vac. The input voltage frequency range should be 47-63Hz. The input and output have good There should be good isolation effect between the input and the output. Output ripple should be limited below 120mV. Other functions such as over-voltage, over-current, over-temperature protection should be taken into consideration. To achieve the above indicators, the design is mainly composed of the following circuits shown in the block diagram of Figure 2:

- *Input Part*: including EMI filter module and rectifier module
- *Power Conversion Part*: including drive module, PWM module, high-frequency transformer module, output filter module and some protection circles
- *Feedback Part*: including voltage sampling module and photoelectric coupling module

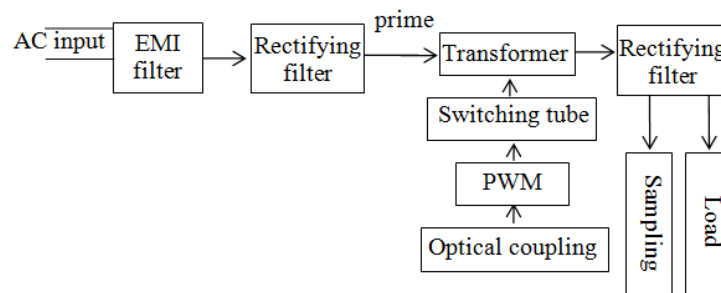


Figure 2. The System framework of flyback switching power supply

4. Caculations to select transformer

4.1. Selection of transformer core

Generally, there are two methods for transformer selection. One is to calculate the required A_P of the core in the system according to the input and output power. Then the appropriate core can be selected after looking up in the core specification table with the solved A_P . The other is to find the serial number of the core in the specification table according to the values of the geometric parameter for design. The former is called A_P method while the latter is called K_G method [9]. In this paper, A_P method is used in the transformer calculation.

4.1.1. Total apparent power. Because the output power is 40.8W, supposed the efficiency $\eta = 0.9$, the input power is $P_{in} = \frac{P_{out}}{\eta} = 45W$. Then the apparent power is $P_T = P_{out} + P_{in} = 85.8W$.

4.1.2. A_P value. Supposed $K_o = 0.4$, $K_f = 4.0$ (square wave), $B_w = 0.2T$, $f_s = 65KHz$. According to some materials, when the temperature is $25^\circ C$, $K_j = 323$, $x = -0.14$, then

$$A_p = \left(\frac{P_T \times 10^4}{K_o K_f f_s B_w K_j} \right)^{\frac{1}{1+x}} = \left(\frac{85.8 \times 10^4}{0.4 \times 4 \times 65 \times 10^3 \times 0.2 \times 323} \right)^{\frac{1}{1-0.14}} = 0.09(cm^4) \quad (1)$$

In order to leave enough allowance and make the diameter of the wire coarser, we choose PQ3220 core. The A_p and A_e value are $1.37 cm^4$ and $170 mm^2$ respectively [9].

4.2. Calculation of transformer parameters

The input voltage of this design is 90-264 Vac. Some other parameters are as follows: switching frequency $f_s = 65 KHz$, pulse maximum duty cycle $D_m = 0.45$. The power conversion efficiency is set to $\eta = 0.8$. There are two output groups. One is the main output 12 V, 3.4 A. The other is the auxiliary

output, providing power supply for the power chip. The voltage set to 20V while the chip's normal current is less than 2 mA. Therefore the power of the auxiliary winding is negligible.

4.2.1. Transformer ratio. When the low frequency ripple is 27V, the minimum input voltage $V_{in(min)} = 90 * \sqrt{2} - 27 = 100V_{dc}$. With the voltage-second balance $V_{in(min)} * D_m = (V_{out} + V_f) * (1 - D_m) * N$, we can get the transformer ratio $N = \frac{V_{in(min)} * D_m}{(V_{out} + V_f) * (1 - D_m)} = 6.294$. Finally, we set the integer $N=7$.

4.2.2. Primary current of transformer. When the output power of the power supply is $P_{out}=40.8W$, the efficiency $\eta = 0.8$, the input power is $P_{in} = \frac{P_{out}}{\eta} = 51W$. The average input current is

$$I_{avg} = \frac{P_{in}}{V_{in(min)} * D_m} = \frac{51}{100 * 0.45} = 1.13A. \quad \text{Supposed } I_{p2} = k * I_{p1}, \quad k=0.4, \quad \text{then}$$

$$I_{p1} = \frac{2P_{in}}{(1+k) * V_{in(min)} * D_m} = 1.619A, \quad I_{p2} = 0.648A \quad \text{and } \Delta I = I_{p1} - I_{p2} = 0.971A.$$

4.2.3. Primary inductance of transformer. From $L_p * \Delta I = V * \Delta t$, we can get the primary inductance of the transformer $L_p = \frac{V * \Delta t}{\Delta I} = \frac{100 * 0.45}{0.971 * 65 * 10^3} = 713\mu H$. Then $I_{p2} = 0.648A$ and $\Delta I = I_{p1} - I_{p2} = 0.971A$.

4.2.4. Transformer turn and air gap. Due to $N_p = \frac{L_p * \Delta I}{A_e * B_w}$, we can get the transformer turn

$$N_p = \frac{713 * 0.971}{170 * 0.2} = 20.36. \quad \text{We set } N_p = 28. \quad \text{Then } N_s = 4 \text{ according to } N = \frac{N_p}{N_s} = 7. \quad \text{Because the thyristor}$$

can only be opened by 3V, we can get $N_{s2} = 1$. Then the auxiliary winding is $N_{aux} = \frac{N_s * (V_{cc} + V_f)}{V_o + V_f} = 6.462$. Finally, we set the integer $N_{aux} = 7$. According to

$$L_p = u_o * u_r * A_e * N_p^2 / l_g, \quad \text{we can get the length of the air gap}$$

$$l_g = \frac{u_o * u_r * A_e * N_p^2}{L_p} = \frac{4 * 3.14 * 10^{-7} * 1 * 170 * 28^2}{713} = 0.235mm.$$

4.2.5. The wire diameter of the winding. Because the wire diameter of the winding depends on the effective value of current, the effective value of the primary current is

$$I_{prms} = \sqrt{\frac{D_m}{3} (I_{p1}^2 + I_{p2}^2 + I_{p1} * I_{p2})} = 0.783A. \quad \text{Similarly, the effective current of the secondary winding}$$

$$\text{is } I_{srms} = \sqrt{\frac{1-D_m}{3} ((\frac{I_{p1}}{N})^2 + (\frac{I_{p2}}{N})^2 + (\frac{I_{p1}}{N}) * (\frac{I_{p2}}{N}))} = 0.124A. \quad \text{We set the current density } I_j = 6A/mm^2.$$

$$\text{Then the primary wire diameter is } d_p = \sqrt{\frac{4 * I_{prms}}{\pi * I_j}} = 0.408mm, \quad \text{while the secondary one}$$

$$\text{is } d_s = \sqrt{\frac{4 * I_{srms}}{\pi * I_j}} = 0.162mm. \quad \text{Therefore, we should set the wire diameters of the primary and secondary}$$

winding as $d_p = 0.4mm$ and $d_s = 0.17mm$, respectively. For power supply winding, it is enough to set the wire diameter as 0.12mm because the current is very small. In order to improve the efficiency and reduce the leak inductance, we use sandwich winding method to wind the transformer. The primary winding comes first. The secondary one comes next. Then it is the auxiliary winding. The primary one comes last.

5. Conclusion

Flyback topology is adopted to design a switching power supply in this paper. In order to realize the given design indicators, the framework is finished with a PWM integrated circuit as the core. It is the key procedure to select the transformer while designing the power supply. Therefore the selection method of the transformer, which is called A_P method, is discussed in detail. Then we decide to choose PQ3220 core according to the solved total apparent power and A_P value. After the calculation of some other significant parameters, we get the details of the transformer as follows: the transformer ratio of 7, the primary current of 1.619A and 0.971A, the primary inductance of 713 μ H, the air gap of 0.235 mm etc. These calculations and parameter settings can guarantee the design demand and the efficiency of the flyback switching power supply.

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