Design of Adjustable Switching Power Supply with Current Type Single-Ended Flyback Output

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Abstract. This study is based on the UC3845 controller, designed a flyback switching power supply, which has a wide input voltage range, high output voltage accuracy, and high load regulation. According to the characteristics of flyback switching power supply and UC3845, adding filter circuit, a feedback circuit, protection circuit, etc., develop a single-ended flyback switching power supply with adjustable output, stable and reliable, and high efficiency. According to the simulation results, it can be seen that the designed switching power supply has high output voltage accuracy, and the input voltage in the range of 200V~240V, the accuracy of the output voltage is kept within 1.3%; the voltage adjustment is less than 1%, The output ripple factor is kept below 0.09%, and the output voltage is adjustable.

1. Introduction
The single-ended flyback switching power supply has been widely used in the power supply of automatic control and intelligent instrument because of its advantages of simple structure and few components [1]. The duty cycle of the power MOSFET is regulated by pulse width modulation (PWM) technology to stabilize the output voltage. This paper used a high-performance integrated control chip UC3845 as a pulse width modulation device. Its main features are an internal oscillator, high-precision error comparator, cycle-by-cycle current sampling-comparison, low start-up current, high-current totem pole output, etc., which are ideal devices for driving MOSFETs [2].

2. Switching power supply circuit design
The whole circuit mainly is included the rectifier and filter circuit, converter (including power switch tube, high-frequency transformer, etc.), control circuit, and a feedback circuit. The circuit diagram is shown in Figure 1.
The circuit set takes the input of 220V AC as an example. After passing through the bridge rectifier circuit and filter circuit, the output is turned to a DC close to 311V. By starting resistor R2 and capacitor C14, the UC3845 is brought to the start condition and can maintain stable operating conditions [3]. When the UC3845 is operating normally, a drive pulse can be provided to drive the MOSFET. The DC voltage can be output through a flyback transformer and rectification filtering [4]. When interference affects the output circuit, feedback adjustment is required to ensure voltage stability. In this paper, the internal error amplifier is forced to output a high level by directly pulling down the voltage of pin 2. The voltage at the output of the error amplifier is regulated by an optocoupler to adjust the duty cycle [5]. That is, the output signal is used as a feedback signal. The feedback circuit formed by the TL431 and the optocoupler is used to regulate the duty cycle of the output pulse. It can also protect the control chip UC3845 from achieving the purpose of stabilizing the output voltage.
3. Circuit design around the chip UC3845

3.1. Power supply circuit
The UC3845 power supply is divided into two phases: the start-up phase and the normal phase. In Figure 1, the starting resistor R2 and capacitor C14 constitute a starting circuit. At start-up, the filtered DC voltage is supplied to the capacitor C14 via the start-up resistor R1. The voltage of C14 must reach the threshold of 8.4V of UC3845’s starting voltage. Otherwise, an undervoltage lockout (UVLO) function is enabled. During regular operation, the UC3845 provides the drive pulse that is driven by pin 6 to operate the switch. In this process, since the current supplied by R2 is not enough to maintain the operating current of UC3842, capacitor C1 is discharged, and the capacitor’s voltage is gradually reduced. The auxiliary power supply must provide the operating voltage before the capacitor’s voltage drops to the cut-off operating voltage of UC3842. The UC3842 was not able to work when the voltage drops to the cut-off operating voltage on C1 [6], while the auxiliary power supply consists of the auxiliary winding, the rectifier circuit, and the filter. Therefore, for regular operation, the starting capacitor C14 must be able to provide enough energy, that is, a sufficiently large capacitance of the capacitor [3]. Capacitor C16 is used to filter out high frequency superimposed signals [7]. According to the chip’s datasheet, the formula for starting resistor is

\[ R_2 = \frac{V_{CC} - V_{C}}{I_{\text{OUTPUT}}} \]  

3.2. Current sampling circuit
This circuit is used to collect the current of the power switch tube to the pin 3, and the pin 3 and the output of the error amplifier inside the UC3845 are determined the duty ratio of the output. Therefore, this circuit plays a feedback role and acts as a current limiter [8]. For sampling resistor R8 its peak circuit is

\[ I_{R8} = \frac{V_{\text{COMP}} - 1.4V}{3R_8} \]  

where \( V_{\text{COMP}} \) is the voltage at the output of the error amplifier. In order to eliminate current spikes and prevent false triggering of the chip, an RC filter circuit is required. Therefore, a filter capacitor C4 needs to be added to this circuit.

3.3. Feedback circuit design
The circuit is used voltage feedback composed of the photocoupler and TL431. The voltage feedback circuit has high precision and is favorable for the stability of the output voltage [9]. For the characteristics of the UC3845, there are two types of voltage feedback circuits. One is to provide a
stable power supply to the optocoupler through the pin 8 and connect the emitter of the optocoupler to the pin 2 of the UC3845 to provide a comparison value for the error amplifier in the chip. It results in its output value, which controls the duty cycle of the output [3]. This article is applied another way to control the duty cycle. As shown in Figure 1, pin 2 of the UC3845 is grounded, and the error amplifier is forced to output the high voltage. The output of the error amplifier is divided by the optocoupler to adjust the duty cycle of the output as shown in Figure 2.

![Figure 2. Feedback circuit.](image)

The role of the TL431 is to provide a reference voltage to the primary side of the optocoupler. According to the characteristics of the TL431, the reference voltage can be changed by varying the resistance to which it is connected [8]. The voltage at the Comp is changed by adjusting the voltage on the secondary side of the optocoupler. Thus, the duty cycle of the output voltage, by which the output waveform can be adjusted. The equation of adjusted output voltage is

\[
V_o = V_{\text{REF}} \times \frac{(R_5 // R_{15}) + R_{17}}{R_{15} + R_{16}}
\]

where \(V_o\) is the secondary side output voltage of the photocoupler, and \(V_{\text{REF}}\) of TL431 is 2.5V.

### 3.4. Primary buffer circuit of the transformer

Due to the fast turn-off and turn-on of the power switch MOSFET, the back electromotive force generated by the inductor is large, causing serious damage to nearby circuits [9]. In order to prevent the destruction of its peak voltage, a buffer circuit composed of a diode and a resistor-capacitor circuit on the primary side of the transformer is shown in Figure 3 [10]. Since the current generated by the coupled inductor of the transformer is large, the values of R3 and C3 should be as large as possible within a reasonable range. For diodes, models with better EMI characteristics and higher reverse voltage should be selected.

![Figure 3. Primary buffer circuit diagram.](image)

### 3.5. Secondary buffer circuit of the transformer

For the secondary side of the transformer, a sharp waveform is generated at the moment when the diode D5 is turned off. If the spike exceeds the withstand voltage of the diode D5, the diode may be
broken down. In order to protect the diode and improve EMI, it is necessary to add the buffer circuit composed of R18 and C8, as shown in Figure 4 [10]. During the adjustment of the buffer circuit, it is necessary to pay attention to the overheating of R18 and C8.

**Figure 4.** Secondary buffer circuit diagram.

4. Simulation Results and Discussion
This paper used Saber to model, simulate and analyze the circuit schematic. The overall circuit of the modelling and simulation is shown in Figure 5.

**Figure 5.** Simulation model by using Saber.

Figure 6 is shown the output voltage waveform when the input voltage is 220V. As shown in the figure, when the power is turned on, the waveform starts to rise sharply, and the final output voltage is stable at 24.103V. According to the accuracy formula of the output voltage is

\[
\delta = \left( \frac{U_1 - U_O}{U_O} \right) \times 100\%
\]  

(4)

where \(U_1\) is the actual output voltage and \(U_O\) is the ideal output voltage.

**Figure 6.** Output voltage waveform.
Therefore, the accuracy is 0.425%, and it is reached the expected design goal. By adjusting the range of the input voltage, the output-voltage accuracy corresponding to different input voltages is obtained, as shown in Figure 7. The input voltage is within 200–240V, and the accuracy of the output voltage can be kept within 1.3%. It shows that the voltage stability of the switching power supply is good, the feedback voltage works normally, the PWM regulation is accurate, and the input voltage is wide.

![Figure 7. Output-voltage accuracy.](image1)

The ripple of switching power supply can be calculated by calculating the ripple factor, as shown in Figure 8. From the simulation diagram, the peak-to-peak value, that is, the output ripple voltage is 0.022V, and the calculated ripple coefficient is

\[
\gamma = \frac{0.022}{24} \times 100\% = 0.09\%.
\]

![Figure 8. Output-voltage ripple.](image2)

In the voltage feedback circuit, adjusting the resistance of the TL431 can change the value of the output voltage. The output voltage can be adjusted by changing R11 and R18 in the simulation model. Through simulation analysis, it is concluded that when the parallel resistance of R11 and R18 is reduced, the output voltage is increased. For the convex wave appearing in front of the waveform, it is mainly used for the secondary side buffer circuit of the transformer to attenuate the convex wave, thereby making the waveform smoother, as shown in Figure 9.

![Figure 9. Convex wave attenuation.](image3)
Figure 9. Adjustment of the voltage after feedback.

Figure 10 and Figure 11 are shown for different values of the output voltage. In Figure 10, the actual voltage of the output 9V is 9.07V, and the actual voltage of the output 12V is 11.93V. In Figure 11, the actual voltage of the output 5V is 5.5372V, and the actual voltage of the output 3.3V is 3.2764V.

Figure 10. 9V, 12V output voltage waveform.

Figure 11. 5V, 3.3V output voltage waveform.

According to the data in the figure, the output voltage is relatively flat, and the response is faster at 9V or higher. For voltages below 9V, the output voltage waveform is affected by the feedback circuit. However, due to the limitation of the feedback circuit parameters, the waveform error below 9V is large. Thus, the overall waveform is relatively flat.

5. Conclusion
This paper is based on the switching circuit designed by UC3845 control chip. For the basic topology of switching power supply, the flyback converter circuit and its control method, the working mode of UC3845 chip and its surrounding sub-circuit and protection circuit are compared systematically. According to the simulation results, the design circuit of this paper has high output-voltage accuracy. For the input voltage in the range of 200V~240V, the accuracy of its output voltage is kept within 1.3%. For high-frequency switching, the strong ripples can cause surge voltage or current, resulting in
burning of electrical appliances. This design is excellent in suppressing ripple, and the ripple is controlled within 0.1%. This result is lower than 0.5% of the current industry. It is seen that power quality is excellent.

6. References

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