Design of Switching Power Supply for Electric Vehicles with UC3842 Chip

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Abstract. This article is applied to UC3842 as a current mode PWM generator component, which is used to construct a single-ended flyback switching power supply with DC48V input and DC12V output. For the analysis of the instability caused by the peak current control, and the slope compensation is $m=0.75m_2$, the duty cycle is no longer interfere with the stability of the system, which can improve the anti-interference ability of the power supply.

1. Introduction

Electric vehicles are currently zero-emission vehicles. As green vehicles, they will bring huge changes to society. DC brushless motors rely on excellent control modules and power supply performance. High-quality and high-performance systems of power supply occupy an important position in the entire electric vehicle system. In the switching power supply, the pulse width modulation (PWM) control circuit has two types of voltage mode and current mode. The current control mode has the disadvantage of the voltage control mode. In the switching power supply, the pulse width modulation (PWM) control circuit has two types of voltage mode and current mode. The current control mode has the advantage of the voltage control mode. Based on the voltage control mode a current feedback loop is added. The inductor current is no longer an independent variable so that the power supply circuit responds to the changes of input voltage and the load. The response is fast, the anti-interference performance is strong, and the loop stability is better [1]. When the peak current control works at the duty ratio $D>0.5$, it results in problems such as open-loop unstable system, subharmonic oscillation, and poor anti-interference ability. Therefore, the slope compensation must be introduced [2]. The flyback converter has a simple circuit structure, a high operating frequency, a stable output voltage, and its transformer can be used as an output filter inductor in addition to isolation. There is no need to add additional output inductors, so adjustments can be made to follow changes in input voltage and load.

2. Performance indicators of flyback switching power supply design

Electric vehicles are generally powered by lead-acid batteries. They are available in 24V, 36V, and 48V versions, but most of the electric vehicles use DC voltages of around 12V. Based on UC3842 PWM control technology, this paper designs the switching power supply with basic parameters such as input voltage DC 36–48V, output voltage 12V/1A, switching frequency 100KHz, duty ratio less than 60%, power efficiency 80%, and ripple voltage less than 500mV.
Figure 1. Schematic of flyback switching power supply.

Figure 2. Block diagram of flyback switching power supply.

Figure 1 is a circuit diagram of a flyback switching power supply designed in this study [3], which can be divided into UC3842 driving circuit, flyback DC conversion circuit, PWM control circuit, voltage feedback and output filter circuit, ramp compensation circuit, etc. The block diagram is shown in Figure 2.

3. The Circuit design of flyback switching power supply

3.1. Drive circuit of UC3842
The driving circuit is composed of a voltage dividing resistor R1 and a Zener diode D3. The input voltage is supplied with a voltage drop across the resistor R1 to provide a chip driving voltage. In order to prevent the input voltage from being too high and damage the chip, the Zener diode D3 is connected to the power supply terminal of the chip to stabilize the voltage.

3.2. Protection circuit of switching tube
Due to the turn-to-turn capacitance of high-frequency transformer and the recovery time of output rectifier diode, the turn-off voltage of the MOS tube is spiked, which may damage the switch. Therefore, the clamp circuit is designed with R2, C2, and D1. When the MOS tube is turned off, the energy in the leakage inductance of the transformer is transferred to C2 and consumed on the resistor R2, thereby effectively suppressing the turn-off voltage spike of the MOS tube.
3.3. Feedback circuit of DC conversion

As shown in Figure 3, the flyback topology is: When the switch Q1 is turned on, the input voltage is applied to the primary side N1 of the transformer, and the transformer stores energy. According to the polarity of the transformer, the induced electromotive force (emf) on the secondary side N2 is positive (up) and negative (down), the diode D is cut off, and no current flows through the secondary side. When the switch Q1 is turned off, the polarity of the induced electromotive force on N2 is negative (up) and positive (down), and the diode D is turned on. During the turn-on of the switch, the energy stored in the transformer is released to the load through the diode D [4].

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U_o = \frac{U_i N_2 D}{N_1 (1 - D)}
\]  

That is, when the input voltage changes within a certain range or the switching power supply is disturbed, the output voltage can be stabilized within the certain range by changing the duty ratio of the switching tube.

3.4. Output circuit after rectification and filtering

The switching power supply performs high-frequency chopping on the DC input and then transmits it through the high-frequency transformer. Therefore, there must be high-frequency noise interference at the output, and the MOS tube also causes high-frequency noise during the high-frequency switching process. Thus, L1, E2, and E3 are used to form an LC filter circuit to filter out the interference of high-frequency noise.

3.5. Voltage feedback circuit

The voltage feedback circuit is mainly composed of TL431 and TLP521. The output voltage is divided by R9 and R10 to the sampling voltage, which is compared with the 2.5V reference voltage provided inside the TL431. When the sampling voltage is equal to the reference voltage, the current flowing through the optocoupler diode does not change, and the voltage feedback to the pin2 of UC3842 is also unchanged, and the duty ratio of UC3842 for the square wave output is also unchanged. The output voltage of the switching power supply is stable (12V). When the output voltage is high, the sampling voltage increases, the cathode potential of TL431 decreases, and the current flowing through the optocoupler diode become larger. Then the voltage of the triode collector that is feedback to the pin2 of UC3842 also becomes larger, and the output of UC3842 is also increased. The duty ratio for the square wave output becomes smaller, thereby stabilizing the output voltage (12V). When the output voltage is low, the sampling voltage is reduced, the cathode potential of TL431 is increased, and the current flowing through the optocoupler diode becomes smaller. Then the voltage of the triode collector that is feedback to the pin2 of UC3842 becomes smaller, then the duty ratio of UC3824 for the square wave output becomes large, which stabilizes the output voltage (12V) [5].

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\text{Figure 3. Schematic of flyback topology.}
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3.6. Slope compensation circuit

Peak current control has excellent load-regulation characteristics and anti-interference ability for the input and is easy to implement current limiting and overcurrent protection, so it is fully applied in switching power supply. In the state of peak current control, when there is a disturbance $\Delta I_1$, the current waveform of inductor changes as shown in Figure 5 and Figure 6.

Let the rising slope of inductor current be $m_1$, and the falling slope is $m_2$, then $\Delta I_2/\Delta I_1 = D/(1-D) = m_2/m_1$. After n cycles, the disturbance error is $(m_2/m_1)^n$. When $D<0.5$, $\Delta I_2<\Delta I_1$, the disturbance error decreases, and after n cycles, the disturbance error decays to 0, and the system is stable. However, when $D>0.5$, the disturbance error increases. After n cycles, the disturbance error gradually enlarges, which leads to the system out of control, and the anti-interference ability of power supply is poor, which cannot work stably [6]. Therefore, the slope compensation must be performed; that is, a signal of a fixed slope is superimposed on the current feedback signal, as shown in Figure 7. Let the slope of the added ramp waveform be $-m$, then $\Delta I_2/\Delta I_1 = (m_2-m)/(m_1+m)$. In order to maintain the stability of the system, there is $(m_2-m)/(m_1+m)<1$. And because $m_1=(1-D)m_2/D$, the ramp slope of the system can be stabilized by adding slope compensation: $m>(2D-1)m_2/2D$, i.e., $m>0.5m_2$. 

![Figure 4. Voltage feedback circuit.](image)

![Figure 5. D<0.5, $\Delta I_2<\Delta I_1$.](image)

![Figure 6. D>0.5, $\Delta I_2>\Delta I_1$.](image)

![Figure 7. Slope compensation.](image)
Normally, the method of slope compensation is to use the sawtooth wave generated by the pin4 of UC3842 to be superimposed on the sampling of current signal pin3 directly by the divider of the resistor, as shown in Figure 8 [7]. The slope compensation circuit composed of RC is simple, but the shunting action of R1 and R2 inevitably affects the charging time of the capacitor, thus affecting the operating frequency of the circuit, and the smaller the R1 and R2, the more significant the effect. Because of this drawback, a triode is added by introducing an emitter follower. The equivalent resistance of the compensation network is increased to reduce the impact of the compensation network on the operating frequency. It is more adaptable than the resistance compensation. The function of the capacitor C8 is to filter out the DC component in the sawtooth wave, as shown in Figure 9 [8].

![Figure 8. RC compensation.](image1)

![Figure 9. Emitter follower compensation.](image2)

4. Simulation results and discussion

The simulation of input and output is shown in Table 1.

| Input voltage/V | 48   | 45   | 42   | 39   | 36   |
|-----------------|------|------|------|------|------|
| Output voltage/V| 11.985 | 11.874 | 11.777 | 11.727 | 11.722 |

When the load current is constant, the voltage-regulation coefficient is $S_r = (\Delta U_o/\Delta U_i) \times (U_i/ U_o)$, as shown in Figure 10.

![Figure 10. Voltage-regulation coefficient for different input voltage.](image3)

It can be seen from Figure 10 that the voltage-regulation coefficient can be controlled within 0.17, and the output voltage stability is useful in the face of input voltage variation. In the peak current mode control, the switching power supply is stable when the duty ratio $D<50\%$, but when the duty ratio $D>50\%$, the power supply is prone to subharmonic oscillation and runaway.
According to the test data, when the duty ratio is $D=58\%$, no slope compensation is performed, as shown in Figure 11. The subharmonic oscillation occurs in the waveform of the switching tube, which makes the system's anti-interference ability weak and the output stability is poor.

By designing the emitter follower, the slope compensation is $m<0.5m_2$. As shown in Figure 12, the anti-interference ability of the system becomes stronger, but subharmonic oscillation occurs at around $T=60\mu s$, which is caused by insufficient slope compensation.

When the slope compensating is $m=0.75m_2$, as shown in Figure 13, the switching tube drive waveform is stable, eliminating subharmonics, achieving significant compensation effects, stronger anti-interference ability, and high output voltage stability. Therefore, when the duty ratio is $D>0.5$, the
slope compensation must be performed. When the slope compensation more significant than 50% of the falling slope of the inductor current is added, the power supply can be operated within the variation range of the duty ratio of 0<D<1. It improves the anti-interference ability, eliminates subharmonic oscillation, and ensures stable operation of the power supply.

5. Conclusion
In this study, the UC3842 was used as the current mode PWM controller to construct the single-ended flyback switching power supply with DC 48V input and DC 12V output. By using Saber simulation, when the input voltage is changed, the voltage-regulation coefficient is always controlled within 0.17. When the duty ratio is larger, the voltage-regulation coefficient is smaller, indicating that the switching power supply has a larger duty cycle and it is more stable. By introducing a relatively simple structure of the emitter follower compensation method, the impact of direct slope compensation on the operating frequency of the system is significantly reduced. Therefore, the compensation method is more adaptable than the RC compensation circuit. When the circuit operates at an excessive duty ratio, the subharmonic hazard is eliminated, the transformer is protected, and additional energy loss is prevented. By introducing the slope compensation circuit, the range of the duty ratio is expanded resulting in the utilization ratio of the transformer is improved. The miniaturization, weight reduction and popularization of the switching power supply are promoted.

6. References
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