2018 11th International Symposium on Computational Intelligence and Design

Design of A High Efficiency Switching Power Supply with Negative Feedback Control

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***Abstract*—This paper introduced a single-terminaled flyback switching power supply with wide input voltage, low output voltage, large current and high efficiency, which is designed based on UC3843 that is a PWM chip. Adopts MOSFET synchronous rectification technology, and designs over-current and over-voltage protection circuit by photoisolator TLP521-1 and adjustable precision shunt regulator TL431. The experimental results show that the power supply has the advantages of good voltage-stabilization effect, simple structure, high regulation rate of load, and high efficiency, so it has perfect production application value.**

Keywords-efficiency; synchronous rectification technology; single-terminaled flyback; regulation rate of load; pulse width modulation; over-voltage protection; over-current protection;

I INTRODUCTION

With the rapid development of electronic technology, various new types of electronic devices are constantly emerging, and these electronic devices can't do without power supply. All this explains that the power supply is the source of power for all electronic devices. Among them, the low-voltage and high-current DC-DC power supply has always occupied a large share of the market demand of module power supply, so its key technology has important research value[1]. At present, the mainstream DC-DC power supply is mostly switching power supply, with PWM controller as the core. The PWM controller is mainly divided into voltage PWM controller and current PWM controller. The voltage PWM controller adjusts the pulse width by the feedback voltage[2]. The current PWM adjusts the duty cycle by comparing the output current signal of inductance winding with the output signal of error amplifier, so that the peak current of the inductor changes with change of error[3]. Compared with voltage PWM, current PWM has high voltage regulation rate and load regulation[4], and the stability and dynamic characteristics of the system are significantly improved, especially its inherent current limiting capability and paralleled current sharing capability, which makes the control circuit simple and reliable[5]. Therefore, in the design of this circuit, UC3843 was selected as the PWM main control chip. The main circuit is designed based on the single-terminaled flyback topology, using MOSFET synchronous rectification technology, with filter in the secondary-side, to realize low voltage, high current, high efficiency switching power supply design[7].

II UC3843 PWM CONTROLLER

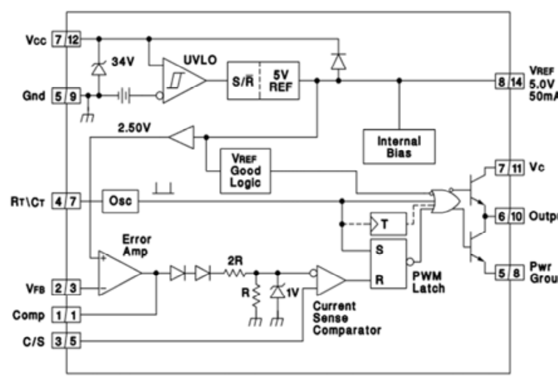

Figure 1. UC3843 constitution block diagram

The UC3843 is a high-performance single-terminaled output current-controlled chip[10]. As shown in Fig. 1, The seventh pin(Vcc) is working voltage terminal of the chip. It needs to input +18VDC voltage when starting up. The sixth pin is the output terminal of the pulse width modulation signal, the fifth pin is the electrical grounding earth terminal, and The eighth pin(Vref) is the leading-out terminal of internal 5.0V reference voltage[6]. The first pin(compensation terminal) is connected to an external RC circuit, which can compensate control circuit. The feedback voltage is obtained through the sampling resistance from output voltage connects to the feedback terminal. The current sampling terminal needs to be connected to an external current sense resistor Rs, and Rs connects in series the source of switching MOSFET Q1. R_T/C_T is a public port for external timing resistors and timing capacitors [9].

The UC3843 has an under-voltage lockout (UVLO) circuit with open threshold voltage of 8.4VDC and shutdown threshold of 7.6VDC. The power supply of the UC3843 can be supplied by a high voltage DC passing through a divider circuit. The differential voltage of open and close of 0.8VDC can effectively prevent the current oscillation when it operates near the threshold voltage [8]. Set a 34VDC Zener diode at the input terminal of UC3843 to ensure that its internal circuit works absolutely below 34VDC to prevent damage caused by high voltage. The reference voltage of 5VDC is led out by 8-pin, and the reference voltage drops down 2.5VDC which provides the reference voltage for the in-phase input terminal of the error

2473-3547/18/$31.00 ©2018 IEEE
DOI 10.1109/ISCID.2018.10129

amplifier. The 5V reference voltage is also used as the power supply for each part of internal circuits. The average current output of UC3843 is ±200mA, the maximum peak current can reach ±1A, and the output low level voltage is 1.5V, and the output high level voltage is 13.5V.

III SWITCHING POWER SUPPLY PRINCIPLE AND CORE CIRCUIT DESIGN

A. Principle of flyback switching power supply

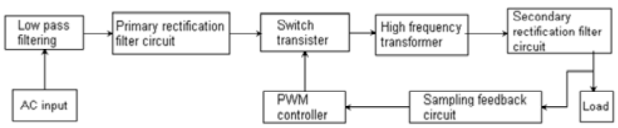

Figure 2. Switching regulated power supply constition block diagram

The whole circuit is mainly composed of PWM control module, and high-frequency transformer output module. The purpose of the design is to convert 220 AC to a 5VDC through PWM, and maintains the power efficiency above 85% for stable and efficient power supply. The overall design idea is that when the power supply of 220VAC passes the low-pass filter circuit (EMI), interference clutter is filtered out, while the power module and the external power grid are isolated. Then one through a rectification filter circuit obtains about 290VDC-300VDC, another through the primary winding of the high-frequency transformer is connected to the drain of the switch MOSFET transistor, and another through voltage divider circuit supplies about 18VDC to the power terminal of UC3843. The sixth pin of UC3843 outputs square wave signal to the gate of the switching MOSFET. The high voltage makes the MOSFET on, primary current inflows the high frequency transformer. The low voltage makes the MOSFET off, and primary current of the high frequency transformer is cut-off. After cutting off, the output voltage of switching transformer's secondary N1, through the MOSFET synchronous rectifies circuit and capacitance filtering circuit outputs stable +5VDC. At the same time, the output voltage of switching transformer's secondary N2, part of which through the diode rectification circuit and voltage-regulator circuit supplies stable 20VDC working voltage of UC3843, and another of which provides break-over voltage to the MOSFET synchronous rectifier transistor, so that the voltage of the secondary N1 of switching transformer can synchronously output.

B. Design of core circuit

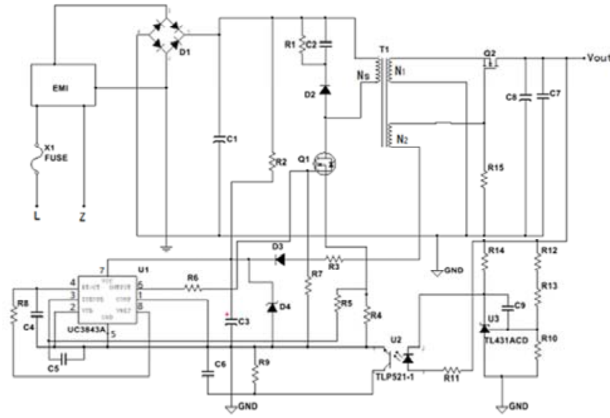

Figure 3. Schematic diagram of a single-terminaled flyback switching power supply

1) Design of pulse width control circuit

The pulse width control circuit includes UC3843 and peripheral circuit. The design requires that when voltage rises to 240VDC, the power supply starts up. The chip's drive current is approximately 0.5mA, and the sampling resistor current is approximately 0.45mA. Therefore, the starting resistance selects R2≈250KΩ, the chip can obtain a starting voltage of approximately 18V during the start-up phase, after circuit stability, the power supply of the chip is supplied by a half-wave rectifying circuit composed of R3, D3, and C3, and the voltage is about 20 VDC. The timing resistor R8 and the timing capacitor C4 is composed of an RC oscillator circuit, which oscillation period determines the period of the output square wave, f = 1.8 / (R8 * C4). R4, R5 and chip 3-pin is composed of the over-current protection circuit of switching MOSFET. If the drain-source current (IDS) of Q1 is too high, the sampling voltage of R4 is compared with the other terminal of the chip's internal current comparator through the chip 3-pin, the output of which will be reversed, 6-pin of the chip will output a low level, and the switching MOSFET Q1 will be cut off, and the high-frequency switching transformer T1 releases the energy stored during the break-over of the switching MOSFET Q1, so that the diodes of N1 and N2 switch into conduction. The square wave signal outputted by the pin-6 of the chip makes break-over and cut-off of the switching MOSFET Q1, so that the output voltage of the second winding of transformer is the switching voltage [9], in which D is the duty cycle, and T is working cycle of the switching MOSFET, Uo /Io represents the output impedance of the flyback converter, and Lp is inductance of primary winding of the high frequency transformer. Q1 selects an enhanced N-channel MOSFET, model :FQPF6N60C (600V/5.5A).The equation of output voltage is shown in (1).

$$U_o = \sqrt{TU_o / 2I_oL_p}\,U_i \qquad (1)$$

2) Design of negative feedback voltage-stabilizing circuits

The negative feedback voltage-stabilizing circuit is mainly composed of a three-terminal regulator TL431 and an opto-isolator TLP521-1. It uses the TL431 to be composed of a precision voltage comparator, and then adjusts output signal accurately through the linear opto-isolator TLP521-1. As shown in Fig. 3, the output voltage is divided and sampled by R12, R13, and R10, and compared with the 2.5V reference voltage of TL431. If the sampling voltage is higher than 2.5VDC, the voltage regulation value of TL431 decreases, and the TLP521-1 control terminal is strengthened. So that the output voltage of the feedback terminal of UC3843 rises, and the output square wave duty cycle of the chip 6-pin decreases, at last the output voltage decreases. If the sampling voltage is lower than 2.5V, the TL431 voltage regulation value increases [11], the break-over of control terminal of TLP521-1 decreases, so the output voltage of the UC3843 feedback terminal decreases, so the duty cycle of output square wave of the chip 6-pin increases, so that the output voltage increases. Therefore, the purpose of voltage regulation is achieved.

3) Design of MOSFET synchronous rectification circuit

This design used a MOSFET synchronous rectification circuit to replace rectifier diode, because the forward voltage drop of the rectifier diode is large. So that the current is large, the power which the diode consumes is large, that will influence on the output voltage and greatly decrease the efficiency of power module. so selects the N-channel MOSFET IRL3102 (20V/61A) as the synchronous rectification MOSFET Q2, which has a very small on-resistance of 0.013 Ω and a small on-state voltage drop, so the efficiency and output voltage loss are very small. The synchronous rectification working principle is: Q1 is the main switching MOSFET, Q2 is the synchronous rectification MOSFET, Ns is the primary winding, N1 is the secondary winding, and N2 is the synchronous rectifier driving winding, which applies gate-source voltage Vgs2 to gate of Q2. The output waveforms of the gate-source voltage Vgs1, Q2's gate-source voltage Vgs2 and drain-source voltage Vds2 when the circuit is working, are shown in Fig. 4.

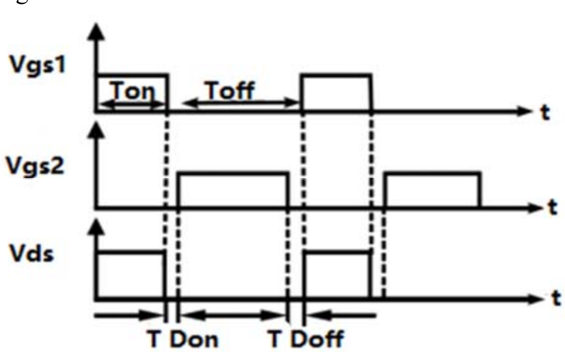

Figure 4. Working voltage waveform of voltage-driven synchronous rectifier

The working principle is: when gate-source voltage Vgs1 of switching MOSFET Q1 is positive, the gate-source voltage Vgs2 of MOSFET Q2 which is driven by N2 winding of switching transformer is negative, then Q2 is cut off because of drain-source voltage is negative. When the gate-source voltage Vgs1 of the switching MOSFET Q1 is positive, the gate-source voltage Vgs2 of MOSFET Q2 which is driven by N2 winding of switching transformer is positive, so MOSFET Q2 is conducted. Including of two-way conduction characteristic of synchronous rectifier transistor, secondary winding current flows from source to drain. At this time, drain-source voltage of the MOSFET Q2 is only 0.04VDC, so the influence on the output voltage is very small, and the efficiency of the power module is very perfect.

4) Design of switching MOSFET protection circuit

In order to prevent the switching MOSFET from being damaged by pulsed peak voltage, when the switch is turned on and cut off, a buffer circuit is designed on the primary winding of the switching transformer to absorb the pulsed peak voltage, which is composed of R1, C2, and D2. The huge electromotive force is generated when current of inductor is cut off, so R1 and C2 should be as large as possible, here ,take R1=10KΩ/4W, C2=34nF/600V, and C2 uses styrene film capacitor, which has excellent high frequency characteristics, D2 uses Schottky diode FR206.

IV RESULTS OF SWITCHING POWER SUPPLY OUTPUT EXPERIMENT

A. Efficiency

The input voltage of the experiment environment is 220VAC.

TABLE I. POWER SUPPLY EFFICIENCY TEST TABLE

Test No.	1	2	3	4
Input power	22.89W	22.78W	21.97W	21.81W
Output voltage	4.871V	4.970V	5.021V	5.143V
Output current	4.124A	4.005A	3.923A	3.892A
Output power	20.09W	19.90W	19.69W	20.02W
Efficiency	87.8%	87.4%	89.6%	91.79%

B. Input and output voltage change information

TABLE II VOLTAGE CHANGE TABLE

Input voltage	198VAC	209VAC	220VAC	235VAC
output current 1A	5.023V	5.034V	5.051V	5.081V
output current 2A	5.076V	5.002V	5.024V	5.010V
output current 4A	4.997V	4.984V	5.007V	5.002V

V CONCLUSION

The high-frequency single-terminaled flyback switching power supply based on UC3843 realized negative feedback regulation of output voltage, obtained a stable output voltage, and improved efficiency by MOSFET synchronous rectification technology. Therefore, the power supply has characteristics of simple structure, excellent voltage regulation performance, high power output efficiency, high load regulation rate, and large output current, which is especially suitable for efficient high-current charging circuit.

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