The Research of High Frequency Soft Switching Power Supply Control Circuit

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Abstract- This thesis mainly introduces a kind of soft switching technology which is named as phase-shifted full-bridge zero voltage PWM control technology, the basic working principle of power factor correction Boost converter and an control chip UC3854 commonly used by Boost converter. The paper designs an control circuit of Boost converter based on UC3854, moreover, it puts forward an improved PFC circuit.

Keywords- switching power supply; phase-shifted full-bridge; PWM; APFC control circuit; UC3854

I. Introduction

As science and technology improves, electronic technology also has a high-speed development. Electronic product comes into every field and continuously improves its performance such as cost effective, beyond that, the function is becoming better and better. At the same time, the power supply circuit plays an important role in switching power supply which begins to be widely used in industry, electricity, transportation and other fields. Modern electronic devices tend to be miniaturization and lightweight. In fact, we have to bear higher frequency of switching power supply to decrease the parameters of the filter and the volume of transformers. In general, the increasing switching frequency will bring the growth of switching loss, decrease the circuit efficiency and strengthen the electromagnetic interference. It is not a good way that only improves switching frequency, so we still need to make the performance of power supply better from other aspects [1].

The basic principle of soft switching is that creates conditions to realize the conversion between switch on and off in the zero voltage or zero current, in order that we can minimize the switching loss and provide the best switching conditions for the device. Phase-shifted controlled full-bridge converter combined the advantages of PWM and soft switching technology. This method achieves PWM control and adjusts output voltage or current without grades at a large scale. Its switching converter works in zero voltage when the power device is converting current, so it has became the most promising soft switching transform circuit. Because of the harmonic pollution caused by the electronic products' widely application, this paper puts forward the power factor correction circuit to make all kinds of power supply devices' side of network current sine and change power factor close to 1, as a result, the higher harmonic current was greatly reduced, in addition, the elimination of powerless loss saves energy.

Above all, this paper designs a full-bridge soft switching power supply control system based on DSP.

II. The Theory of Phase-shifted Full-bridge Zero Voltage PWM

In order to improve the efficiency, decrease the volume, increase the reliability, this paper uses the phase-shifted controlled full-bridge transform circuit. It not only integrates the advantages of PWM with soft switching technology, but also simplifies the circuit (as shown in figure 1) without adding auxiliary switches or any other components compared with the hard switching full-bridge circuit, just uses a resonant inductance to keep the four switching devices in circuits connected in zero voltage. These owe to its unique controlling method. This paper will analysis the several features of phase-shifted full-bridge circuit's control mode on the basis of following graphs [2]:

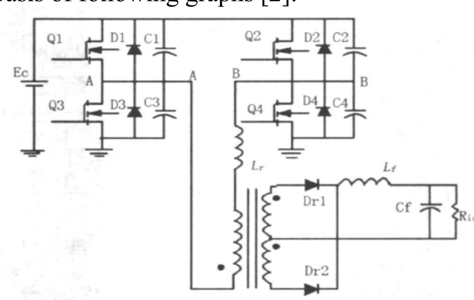

Figure1. Phase-shifted full-bridge zero voltage PWM circuit

- Each switching's connect time is slightly smaller than Ts / 2, but the disconnect time is bigger than Ts /2 in one switching cycle Ts.
- Two switches that one is up and another is down in one same half-bridge can not connect at the same time because there is a certain dead space from one's switching off to another's switching on.
- When you compare the two pairs of switches' waveform which are diagonal, Q1's waveform is ahead of Q4's about o to Ts / 2, and Q3's waveform is before Q2' s too. One pair is called Q1 and Q4, the other pair consisted by Q2 and Q3. Q1 and Q3 were leading-leg, and Q2 and Q4 were lagging-leg.

We assume switches are ideal and ignore the loss in circuit when we analyze it. There are six procedures in this working process, because two switches are symmetrical

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DOI 10.1109/ICNDC.2012.40

which are in the position of diagonal, this paper only analyzes Q1and Q4 's turn-off transient in zero voltage.

A. Q1's turn-off transient

The primary current transfers from Q1 to C3 and Q3 when Q1 shutdowns in zero voltage with C3 and C1. At this time, Lr and Lf (output inductance) is series, and the primary current can be approximately regarded as keep constant. The voltage on C1 and C3 are:

$$U_{C1} = \frac{I_1}{2C_{lead}} t \tag{1}$$

$$U_{C3} = U_{in} - U_{C1} \tag{2}$$

I_1 is the primary current when Q1 shutdowns, C_{lead} is Q1 and Q2's shunt capacitance, U_{in} is input voltage, t is the time of capacitor for recharging.

B. Q4's turn-off transient

The primary current is provided by C2 and C4 when Q4 shutdowns. At this time, I_2 as primary current is used to remove the charge on the C2 and recharges C4 simultaneously. With the existence of C2 and C4, Q4 shutdowns in zero voltage. Therefore, when Q4 shutdown, the original current I_2 and the voltage on C2 and C4 can be achieved as follows [3]:

$$I_2 = I\cos\omega(t - t_2) \tag{3}$$

$$U_{C4} = Z_p I \sin\omega(t - t_2) \tag{4}$$

$$U_{C2} = U_{in} - U_{C4} \tag{5}$$

t_2 --the moment when Q4 shutdowns

ω --radian frequency

$$\omega = \frac{1}{\sqrt{2L_r C_{lag}}} \tag{6}$$

C_{lag} is the Shunt capacitance of Q2 and Q4

Z_p --Resonance resistance

$$Z_p = \sqrt{\frac{L_r}{2C_{lag}}} \tag{7}$$

III. CONTROL SYSTEM DESIGN

A. Overview of control system

Power factor correction as a typical application of power electronic power conversion has great significance in engineering. In addition, this paper will use digital control to correct the power factor of high frequency switching.

In middle or high-power circuit, inductive current often uses continuous manner (CMM) to reduce the peak current. It commonly controlled by average current-controlled Boost PFC, because the Booster inductance L_f is a little big. Its diagram of principle is showed in figure 2:

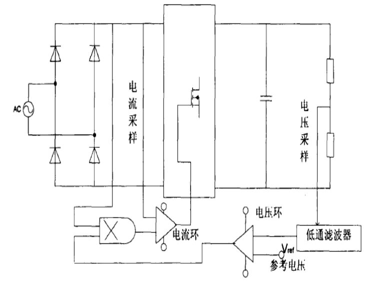

Figure2. Average current-controlled Boost PFC

The control system is controlled by two rings. One controlled ring is used to keep voltage stable (outer ring) and another controlled ring is used to control the waveform of input current (inner ring).Each loops have benchmark, sampling, error amplificatio and other sections. Two control loops connect together through multiplier to control the drive switching frequency's pulsed voltage's pulse width. It also achieves the controlled performance by adjusting the duty cycle of power transistors.

In order to improve the performance of switching power supply, the power supply needs to add some affiliated circuits: the first one is the circuit to protect power supply, it includes over-voltage and over-current protection, input under-voltage protection, under-voltage latch, short circuit protection and so on. The second one is soft-starting control circuit, it not only ensures the power supply stable, reliable and orderly work, but also prevents voltage or current overshoot when it startups; The third one is surge absorber circuit which prevents output ripple peak-peak over-high, high frequency radiation and high-order harmonic caused by Surge voltage Current, at the same time, we need to pay attention to restrain the noise. Its design is showed in figure 3:

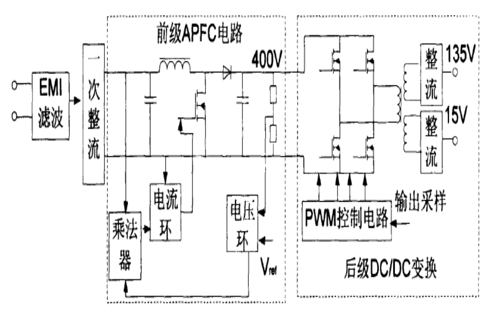

Figure3. The design of switching power supply

B. The analysis of APFC control circuit based on UC3854

On the one hand, digitization makes power electronic control more flexible if CPU computing speed allows, it implements a complex control algorithm which is difficult for simulation control. On the other hand, digital circuits are intrinsically less vulnerable to the effects of environment, it increases system reliability. The paper studies the transfer characteristic from a duplex output of view. Pre-stage main circuit is Boost PFC. The chip UC3854 makes up of control circuit, and it uses push-pull output-stage which makes its output current can reach more than 1A. Thus, the output fixed frequency PWM pulse output can drive large power MOSFET.

Current closed-loop control structure and transfer function Current closed-loop which is composed by current error amplifier, PWM comparator and power lever. Transfer function of each part as follows, current error amplifier is PI corrector as shown in figure 4:

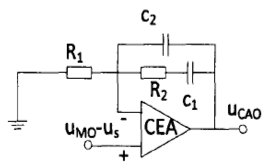

Figure4. Current error amplifier

The transfer function is:

$$G_{CEA} = \frac{U_{CAO}}{U_{MO} - U_S} = \frac{1 + C_1 R_2 s}{R_1 C_1 s (C_2 R_2 s + 1)} \tag{8}$$

The transfer function of PWM comparator is:

$$G_{PWM} = \frac{D(S)}{U_{CAO}} = K_{PWM}$$, $D(S)$—PWM pulse duty cycle

The transfer function of power lever:

$$G_{PS} = \frac{U_S(S)}{D(S)} = \frac{U_O D(S) R_S}{D(S) SL} = \frac{U_O R_S}{SL} \tag{9}$$

$U_S(S)$ --the voltage on sensing resistors R_S

U_O --the output voltage of power circuit (constant voltage)

R_S --current sensing resistors

L--power circuit inductance

The current ring structure as shown in figure5:

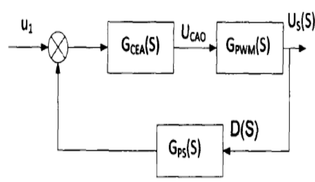

Figure5. The current ring

The current ring open-loop transfer function:

$$G_1 = G_{CEA}(S) G_{PWM}(S) G_{PS}(S) = \frac{K_{PWM} U_O R_S (1 + C_1 R_2 S)}{S^2 L R_1 C_1 (1 + C_2 R_2 S)} \tag{10}$$

Because of second -order zero error system of current loop, it can track sine wave input function so that the current I_L can track I_{MO} without fault.

Voltage closed-loop control structure and transfer function External voltage ring is composed by voltage error amplifiers, multiplier and components which centre on current loop.

The structure as shown in figure 6:

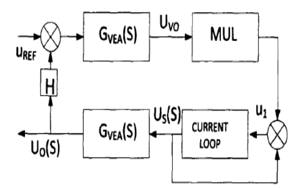

Figure6. APFC double closed-loop system structure

H is the shared-voltage network which is consisted by R_1 and R_2 . The voltage error amplifier as shown in figure 7:

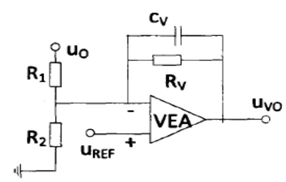

Figure7. Voltage error amplifier

Transfer function is:

$$G_{VEA}(S) = \frac{U_{VO}}{U_{REF} - U_F} = \frac{R_V}{R_1} * \frac{1}{1 + S R_V C_V} \tag{11}$$

Because the voltage ring consists mainly by current ring except for voltage error amplifier, figure 6 can be simplified as structure diagram showed in figure 8:

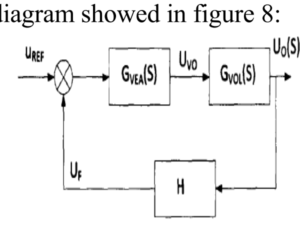

Figure8. Simplified voltage closed-loop structure

Control component includes current loop, and its transfer function $G_{VOL}(S)$ is:

$$G_{VOL}(S) = \frac{U_O(S)}{U_{VO}(S)} = \frac{P_{IN}}{S C_O U_O \Delta U_{VEA}} \tag{12}$$

P_{IN} --Input power

C_O --Power circuit capacitance value

U_O --Output DC voltage

ΔU_{VEA} --Maximum range output voltage of voltage error amplifier

The transfer function $G(S)$ for voltage open-loop system:

$$G(S) = G_{VEA}(S)G_{VOL}(S) = \frac{P_{IN}R_V}{SU_O R_1 C_O \Delta U_{VEA}(1 + C_V R_V S)} \quad (13)$$

The system is one-order zero error system, it can track input signal with no fault, that is to say, output is stable if U_{REF} is taken as a given.

C. *Feedforward voltage filter structure and transfer function*

Because voltage has high-order harmonic in appreciable quantity after rectifying, it will eventually cause the input current distortion if harmonic goes through multiplier. The feedforward voltage ripple should be very small. System uses double-pole filters for the attenuation of feedforward voltage ripple as shown in figure 9. The transfer function is [4]:

$$G_K(S) = \frac{U_2(S)}{U_1(S)}$$

$$= \frac{R_3}{R_1R_2R_3C_1C_2S^2 + R_1C_1(R_2+R_3)S + R_3C_2(R_1+R_2)S + R_1 + R_2 + R_3}$$

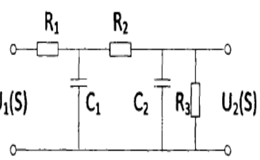

Figure9. Feedforward filter

IV. *Conclusion*

This switching power supply adopts two-stage converter, the pre-stage circuit uses average current-controlled Boost PFC control circuit which is controlled by UC3854 to improve circuit power factor. It not only reduces the harmonic pollution of the power supply for grid but also makes the switch in the converter work in the state of soft switch. The post-stage DC/DC part adopts phase-shifted full-bridge ZVS PWM transform circuit without any auxiliary circuit, just uses switch stray capacitances and transformer leakage resonance that will realize zero voltage switch. Six switches of the power supply are working in soft switching state, so the power supply has the high power factor, high efficiency, low cost, easy realization and other advantages, these will have very strong practicability.

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