A Zero-voltage-transition PFC Circuit Based on IC UC3855

Lisheng Shi Limin Chen
North China Electric Power University,
Baoding, P.R. China, 071003

Baojiang Chen
Shenzhen Huawei Tec.Co.,Ltd.
Shenzhen , P.R. China, 518054

ABSTRACT-This paper introduces the advantages of zero voltage transition(ZVT) boost converter for power factor correction and analyzes the control method of ZVT with IC UC3855. Practical design issues which include the components selection and design procedure are discussed. The experimental results are given.

1. INTRODUCTION

Since the zero voltage transition (ZVT) PWM converter has been proposed, ZVT-PWM converter technology is playing an important part in power electronics. ZVT-PWM converter technology combines the advantages of the conventional PWM and the soft resonant techniques. Its advantages are summarized as follow [2]:

1) Both the active and passive switches operate with zero-voltage switching;

2) Both switches are subjected to minimum voltage and current stresses same as those in their PWM counterparts;

3) Soft-switching operation can be easily maintained for wide line range and load range;

4) The switching frequency is constant.

For engineering purpose, the realization of ZVT-PWM technique control strategy and practical design procedure is more important than simple principle analysis only. The purpose of this work is to investigate the ZVT PFC circuit based on IC UC3855. The power stage and the specialized control method are analyzed in this paper. The optimum selection of ZVT-PFC circuit components is discussed. Finally, A ZVT-PWM PFC circuit is designed and the experiment results are given.

2. PRINCIPLE OF ZVT-PWM CONVERTER

Circuit composition of ZVT-PWM converter

Figure 1 is the boost ZVT-PWM converter[2]. From the figure, we can see that it is different from the conventional boost PWM converter by possessing an additional active resonant network consisting of a resonant conductor(Lr), an auxiliary switch (S1),and a diode (D1). Cr is the resonant capacitor, which incorporates the output capacitance of the power switch.

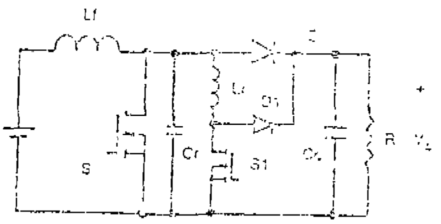

Fig.1 Circuit diagram of ZVT-PWM converter

Main waveforms of ZVT-PWM converter

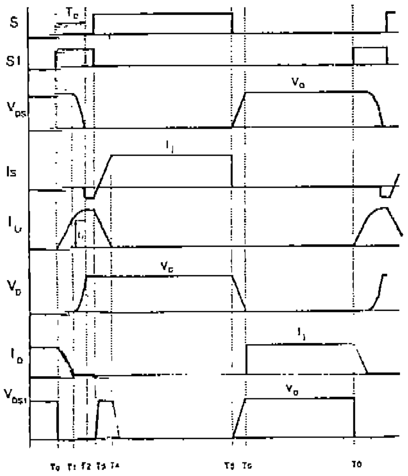

Fig. 2 The main wavefoms of ZVT-PWM converter

3. CONTROL METHOD OF UC3855

Description of UC3855

UC3855 is the integrated chip for the boost ZVT-PWM PFC purpose. This is the only integrated chip that we can find in market at present. It is the product of Unitrode Integrated Circuit Corp. The UC3855 provides all the control features necessary for high power, high frequency PFC boost converters. It is the average current mode control method that used by UC3855. This kind of control method allows for stable, low distortion AC line current programming without the need for slope compensation. Figure 3 is the block diagram of UC3855. From figure 3, we can see that the UC3855 also features a single quadrant multiplier, squarer, and divider circuit which provides the programming signal for the current loop. The internal multiplier current limit reduces output power during low line conditions. An overvoltage protection circuit disables both controller outputs in the event of a boost output overvoltage condition. Low startup supply current, UVLO with hysteresis, a 1%7.5V reference, voltage amplifier with softstart, input supply voltage clamp, enable comparator, and overcurrent comparator complete the list of features. Available packages of UC3855 include:20 pin N,DW,Q,J, and L.

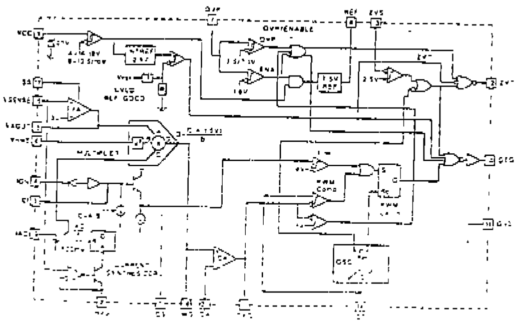

Fig.3 The block diagram of UC3855

Realization of ZVT-PWM based on UC3855

Realization of PFC

Figure 4 is the block diagram of UC3855 PFC control principle. From Figure 4, we can see that there are two control loops, which are the input current loop and output voltage loop. The rectified line voltage programs the current loop so that the input to the converter will appear to be resistive. Changing the average amplitude of the current programming signal controls the output voltage. An analog multiplier creates the current programming signal by multiplying the rectified line voltage with the output of the voltage error amplifier so that the current programming signal has the shape of the input voltage and an average amplitude which controls the output voltage.

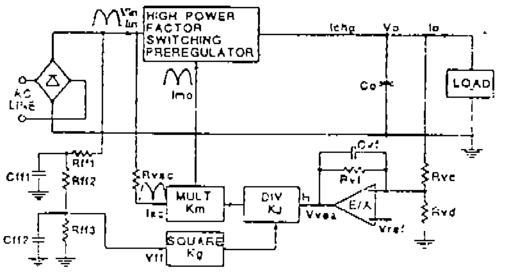

Fig.4 The block diagram of PFC control principle

$$C_o = \frac{2 \times P_{out} \times \Delta t}{V_o^2 - V_{o(\min)}^2} \tag{1}$$

Figure 4 shows a squarer and a divider as well as a multiplier in the voltage loop. The output of the voltage error amplifier is divided by the square of the average input voltage before it is multiplied by the rectified input voltage signal. This extra circuitry keeps the gain of the voltage loop constant, without it the gain of the voltage loop would change as the square of the average input voltage. The average value of the input voltage is called the feed forward voltage since it provides an open loop correction, which is fed forward into the voltage loop. It is squared and then divided into the voltage error amplifier output voltage. The current programming signal must match the rectified line voltage as closely as possible to maximize the power factor. If the voltage loop bandwidth were large it would modulate the input current to keep the output voltage constant and this would distort the input current horribly. Therefore the voltage loop bandwidth must be less than the input line frequency. But the output voltage transient response must be fast so the voltage loop bandwidth must be made as large as possible. The squarer and divider circuits keep the loop gain constant so the bandwidth can be as close as possible to the line frequency to minimize the transient response of the output voltage. This is especially important for wide input voltage ranges.

The circuits, which keep the loop gain constant, make the output of the voltage error amplifier a power control. The output of the voltage error amplifier actually controls the power delivered to the load.

Realization of ZVT

Figure 5 is the block diagram of UC3855 ZVT control principle. From figure 5, we can see that the realization of ZVT based on UC3855 is mainly determined by the ZVTOUT and ZVS pins.

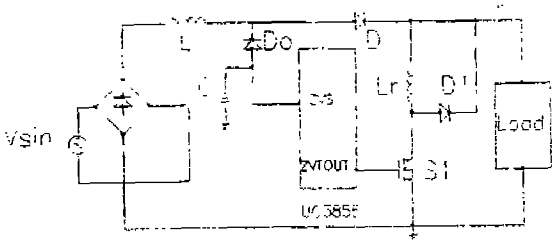

Fig.5 The block diagram of ZVT control principle

ZVS pin senses when the drain voltage of the main MOSFET switch has reached approximately zero vlots, and resets the ZVT latch via the ZVT comparator. A minimum and maximun ZVTOUT pulse width are programmable from this pin. To directly sense the drain turned-off voltage of the main switch, a blocking diode is connected between ZVS and the high voltage drain.. when the drain voltage reaches 0V, the level on ZVS is about 0.7V which is below the 2.6V ZVT comparator threshold. The ZVTOUT pulse width is approximately equal to the oscillator blanking period time.

The output of the ZVT block is a 750mA peak totem pole MOSFET gate driver on ZVTOUT pin . Since the ZVT MOSFET switch is typically 3X smaller than the main switch, less peak current is required from this output.

4. DESIGN OF ZVT-PWM PFC CIRCUIT

Power stage design

Switching frequency selection

Since UC3855 is developed from UC3854, the power stage design procedure is almost the same as the UC3854 PFC circuit. But for the ZVT-PWM PFC circuit, the main switch is turned on with zero voltage and the freewheel diode is turned off with zero current. These two advantages allow the switching frequency of the main switch much higher than the UC3854 PFC circuit. ZVT-PWM PFC converter switching frequencies up to 500kHz are realizable. The choice of switching frequency is generally somewhat arbitrary. The switching frequency must be high enough to make the power circuits small and minimize the distortion and must be low enough to keep the efficiency high.

Boost inductor selection

The boost inductor determines the amount of high frequency ripple current in the input and its value is chosen to give some specific value of ripple current. The detailed design procedure of the inductor is in [1].

Output capacitor

The output capacitor is determined by the following equation[1]:

Where Co is the output capacitor, Pout is the load power, ⊿t is the hold-up time, Vo is the output voltage and $V_{o(min)}$ is the minimum voltage the load will operate at.

Main switch and freewheel diode selection

In boost ZVT-PWM PFC converter, the freewheel diode is commutated at much lower di/dt than in a conventional boost PFC converter based on UC3854. But for optimum performance, the freewheel diode should have very fast reverse recovery. It is much better if the diode have soft recovery characteristics. The main switch is selected as in a conventional boost PFC converter based on UC3854[1].

Auxiliary switch selection

Since the auxiliary switch operates in hard switching, the switching and conduction losses must be considered carefully. In [3], the auxiliary switch RMS current can be expressed by equation (2). This equation helps us to select the auxiliary switch.

$$I_{QZVT}\,(rms) \approx I_{ip}\sqrt{\frac{t_{ZVT}}{2T}} \qquad (2)$$

Where I_{ip} is the peak input current of boost inductor, T is the switching period of main switch, t_{ZVT} is the auxiliary swtch on time interval.

Resonant circuit design

Resonant capacitor selection

The resonant capacitor includes two parts, one is the output capacitance of the main switch, and the other is the capacitor that is connected drain to source on the main switch. For practical design, the latter one's value is approximate two to six times the first one. Thus the gate drive can be relaxed and the EMI from high dv/dt can be reduced.

Resonant inductor selection[4]

The resonant inductor value is chosen to limit turn on di/dt to an acceptable level. This value is difficult to calculate accurately because of the recovery characteristic variation among different rectifiers. The final resonant inductor value must ultimately be determined empirically using the manufacture's data to initially select the components.

Rectifier D1 selection

Rectifier D1 is primarily selected for reliable peak current operation since its average current is relatively low. The type of diode D1 should be fast recovery one, which has soft characteristics.

5. RESULTS OF EXPERIMENT [5]

Experiment parameters

Line voltage (RMS) : V_{in}=85V-253V
Output power (max) : Po=500W

Output DC voltage: 400V
Output capacitor C_o=450uF
Line frequency : f=50Hz
Boost inductor : L=0.5mH
Main switch switching frequency : fs=100kHz
Main switch: IRF840
Auxiliary switch: IRF640
Freewheel diode : MUR8100
Resonant capacitor: C_r=5nf
Resonant inductor: Lr=20uH
Resonant circuit rectifier D1: UHVP206

Key experimental waveforms

Figure 6 is the voltage and current waveforms of line. Figure 7 is the drain voltage and source current waveforms of main switch. Figure 8 is the gate voltage and drain voltage waveforms of auxiliary switch. Figure 9 is the resonant inductor current waveform.

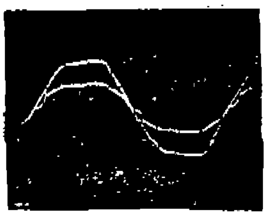

Fig. 6 Voltage and current waveforms of line

Fig.7 Drain voltage and source current waveforms of main switch

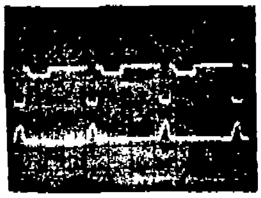

Fig.8 Gate voltage and drain voltage waveforms of auxiliary switch

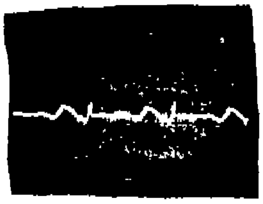

Fig.9 Resonant inductor current waveform

Test results

Power factor: PF=0.997, Total harmonic distortion:THD<5%. Figure 10 is the relations between efficiency and line voltage with ZVT soft switching and hard switching. Figure 11 is the relation between efficiency and output power.

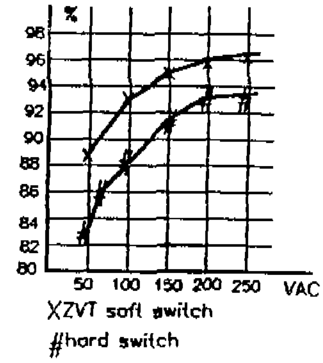

Fig.10 Efficiency and line voltage

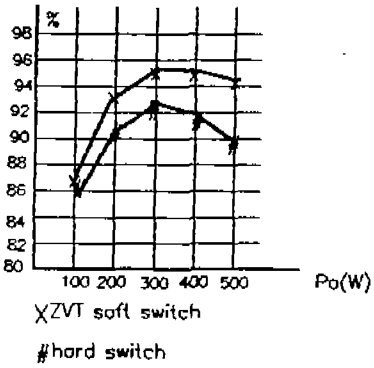

Fig. 11 Efficiency and output power

Table I is the harmonic distortion of the line current.

Order(n)	1	3	5	7	9	11
Distortion(I_n/I_1%)	100	1.6	1.3	2.4	0.5	0.2

6. CONCLUSIONS

The ZVT-PWM PFC converter based on UC3855 have many advantages:

1) Nearly unity power factor.
2) Low line harmonic current distortion less than 5%.
3) Average current control mode and continuous boost inductor current.
4) High efficiency.
5) Constant frequency control.
6) Soft switching of main switch and freewheel diode.

7. REFERENCES

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