A NOVEL ZVS-CV PWM AC-DC CONVERTER

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ABSTRACT-A new ZVS-CV PWM converter with power factor correction (PFC) function is presented in this paper. The new topology is a integration of a boost converter and a ZVS-CV topology in a single power conversion stage. The new converter can be regulated in pulse-width modulation (PWM) by universal integrated control circuits. Some design considerations are given in detail. A laboratory prototype has been implemented to show the feasibility of the approach and the analysis.

1. INTRODUCTION

The pulewidth modulated (PWM) boost converter is widely used in many applications, most notably as a high power factor preregulator for power supplies where the boost converter operates at continuos conduction mode (CCM) or discontinuous conduction mode (DCM). When the converter operates in DCM , the switch is controlled only by one factor, i.e., the feedback of the output voltage. Being in proportional to the input voltage in each working cycle, the average current through the input inductor follows the input voltage with a sine waveform automatically. Since only one control loop is needed, this method is getting more appealing to researchers because it is much simpler and less costly. It also has several problems, such as larger switching losses and EMI. These problems hinder the operation of the converter at high switching frequencies.

Recently several converters have been proposed to try to correct these problems[1,-3]. These converters general have one or more auxiliary switch that is used to ensure that the main switch is turn on or turn off under soft-switching conditions. But some new problems are created by these converters, such as, high voltage and/or large current stresses on the switch which cause larger conduction losses, power and control circuit are complex.

We present in this paper a new PFC circuit based on combining boost and ZVS-CV step-down converter in a single power conversion stage to solve the problems above. By appropriate design, the input inductor works in its DCM to achieve PFC function, just like the inductor in a boost converter operating at its DCM, while the switches are lossless in the proposed topology because they can be turned on and turned off at zero voltage. On the other hand, the voltage on the switches are clamped at a value same as in boost converter, which is different from that in a resonant switching topologies. In the paper, the modes of operation of the converter are explained and analyzed. A laboratory prototype has been implemented to show the feasibility of the approach and the analysis.

2. PROPOSED TOPOLOGY

The proposed PFC circuit has been shown in Fig.1. Where L_f and C_f is a low pass filter, a boost converter has been formed by inductor L_1 , switch S_1 , diode D and D_2 , a buck converter has been formed by switch S_2 , diode D_2 and inductor L_2 , and C_1 , C_2 are resonant capacitors. C_M is just like the capacitor in traditional boost dc-dc converter, it can be seen as the power supply of the buck converter simultaneously. The switches S_1 and S_2 are turned on and turned off alternatively. The operating mode of inductor L_1 is the same as that in PFC boost converter .

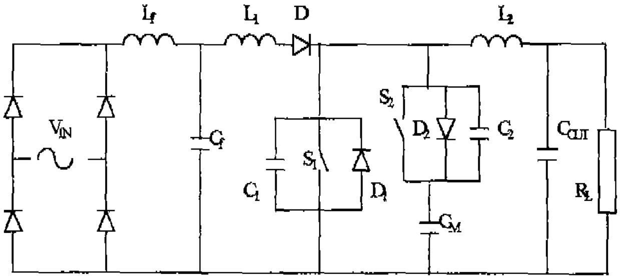

Fig.1 The proposed PFC circuit

At the instant the switch S_1 is turned off,. T_1 is turned off at zero voltage because of C_1; the voltage across T_1 builds up slowly compared with its switching time. With T_2 off and T_1 just off, the equivalent resonant circuit is shown in Fig.2. At the instant the switch S_2 is turned off, because of the diode D_1, the switch S_1 turned on at zero voltage.

At the instant the switch S_2 is turned off, T_2 is turned off at zero voltage because of C_2; the voltage across T_2 builds up slowly compared with its switching time. With T_1 off and T_2 just off, the equivalent resonant circuit is shown in Fig.3. At the instant the switch S_1 is turned off, because of the diode D_2, the switch S_2 turned on at zero voltage. The equivalent resonant circuit is shown in Fig.3.

In Fig.2 and Fig.3, the capacitor C is the parallel value of C_1 and C_2[4].Since C is very small, the resonant frequency is much larger than the switching frequency of the converter.

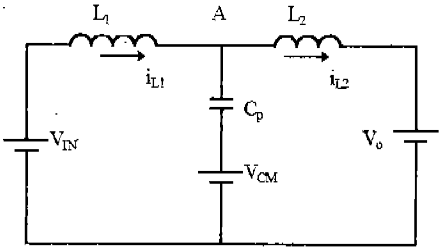

Fig.2 The equivalent resonant circuit I

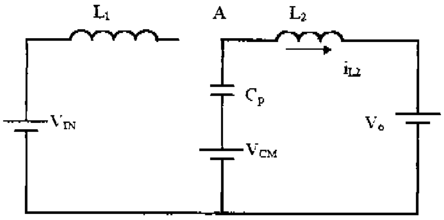

Fig.3 The equivalent resonant circuit II

3. SOME DESIGN CONSIDERATIONS

3.1 Critical Conditions

In order to achieve PFC, the inductor L_1 must operate in its DCM. According to the point of energy balance[5],the corresponding dimensionless parameter of L_1 is

$$K_{L1} = \frac{1}{\pi}\frac{d^2}{(1-d)^2}\frac{1}{(M')^2} f(M') \qquad (1)$$

where

$$M' = \frac{V_{CM}}{V_P} \qquad (2)$$

and V_{CM} is the voltage on capacitor C_M, V_P is the peak value of the input line voltage.

When the input voltage is at its peak, assuming that L_1 operates at the boundary between DCM and CCM, M' will be

$$M' = \frac{1}{1-d} \qquad (3)$$

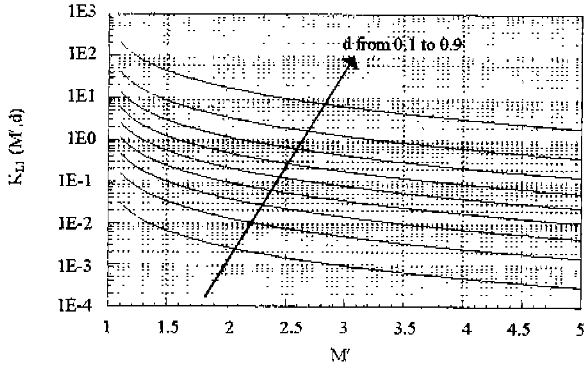

Fig.4 The relationship between K_{L1}, M' and d

The critical condition of L_1 is

$$K_{L1,B}^{PFC} = \frac{d^2}{\pi} f(\frac{1}{1-d}) \qquad (4)$$

Considering the efficiency η of a converter, the critical condition of L_1 will be

$$K_{L1,B}^{PFC} = \eta\frac{d^2}{\pi} f(\frac{1}{1-d}) \qquad (5)$$

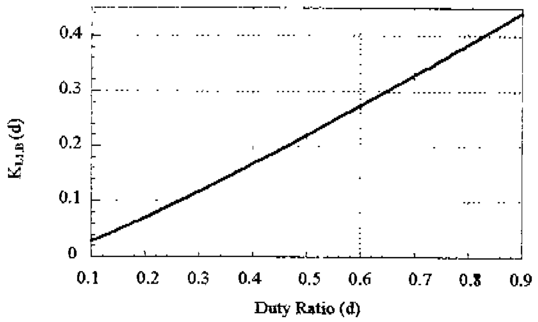

Fig.6 The theory curve of $K_{L1,B}^{PFC}$

When $K_{L1} < K_{L1,B}$, L_1 should operate in its DCM.

We can also express the critical condition by means of equivalent dimensionless parameter

$$K_{L1E} = \frac{2L_1}{R_E T_S} \tag{6}$$

where R_E is the load of equivalent Boost converter[], therefore

$$K_{L1E}' = \frac{2L_1}{R_L T_S}(1-d)^2 \tag{7}$$

Combing eq.(7) and eq.(1), we can obtain

$$K_{L1E} = \frac{1}{\pi}\frac{d^2}{(M')^2} f(M') \tag{8}$$

The corresponding critical condition is

$$K_{L1E,B}^{PFC} = \frac{1}{\pi} d^2 (1-d)^2 f(\frac{1}{1-d}) \tag{9}$$

3.2 Inductor L_2

When the switch S_1 is just turned off, the current through inductor L_1 is

$$i_{L1}(t) = \frac{V_{IN} d T_S}{L_1} \tag{10}$$

It is obviously that the current through inductor L_1 is varying with the input line voltage. If the current through inductor L_2 is larger than that of L_1 at the switch S_1 just turned off, the voltage at point A can not vary. At this time, the switch S_2 can not be turned off at zero voltage condition but must discharge the capacitor C_2 also, a large pulse current appears on the switch S_2. Because of the current through inductor L_1 is almost zero at the switch S_1 just turned off when the input line voltage is at zero, the inductance of L_2 must reach zero or reverse at this time to ensure the ZVS condition. So one can get

$$L_2 \le \frac{V_O d T_S}{i_{L2,P}} \tag{11}$$

where $i_{L2,P}$ is the peak current of inductor L_2.

4. SIMULATION AND EXPERIMENT RESULTS

A design example is given to show the feasibility of the approach and the analysis. The data is:

input voltage $V_{IN}(t) = 110 Sin wt$, $\omega = 100\pi$;

output voltage $V_O = 180V$;

$f_S = 50kHz, T_S = 20\mu S$;

output power $P_O = 150W$;

In order to guarantee L_1 to be in DCM, L_1 is selected to be 200μH as $L_{1,B}^{PFC} = 216\mu H$ according to eq. (4) or eq.(9), and L_2 is selected to be 800μH as $L_{2,B}^{PFC} = 864\mu H$ calculated from equation (11) to ensure the ZVS condition. The diode D is a MUR860 and the switches are IRFP450.

The SPICE simulation results for the design example are shown in Fig.6.

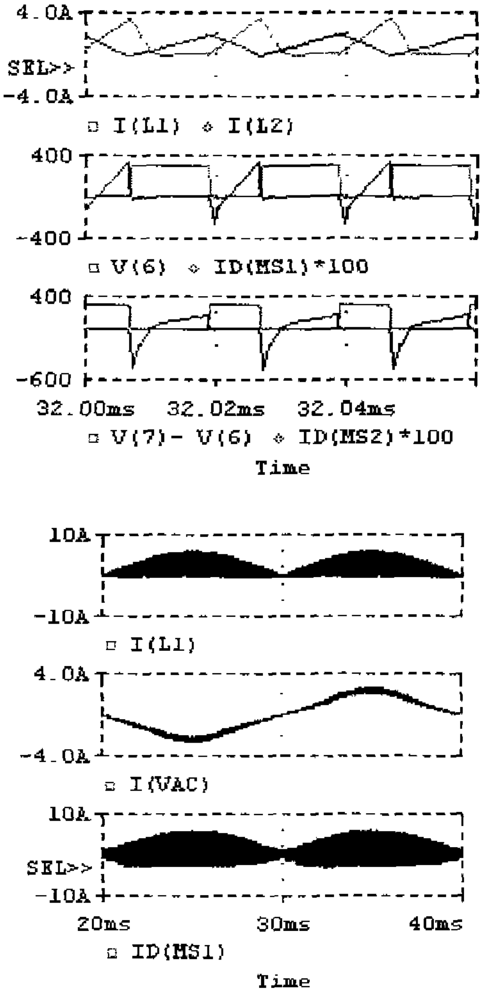

Fig.6 SPICE Simulation Results

From the current waveforms of inductor L_1 and L_2, we can see that the inductor L_1 operates in its DCM, and the current through L_2 is zero when switch S_1 is just turned off. These are important for obtain high power factor and ensure ZVS condition. The input current in a line period is a good sinus waveform

From the voltage and current waveforms of two switch we an see that the diode D_1 and D_2 conduct before the switches S_1 and S_2 conducting. This is the key of the switches turned on at zero voltage condition.

The important experiment results are shown in Fig.7 and Fig.8.

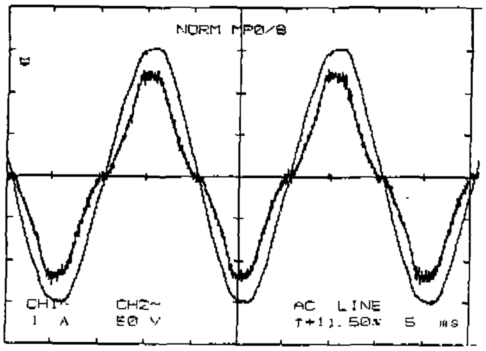

Fig.7 The input line current and voltage

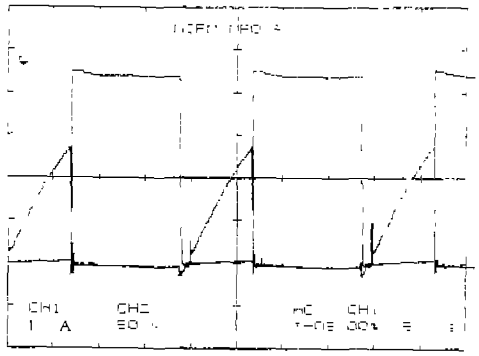

Fig.8 The voltage and current on switch S_1

The experiment results are consistent with the simulations and the analysis.

5. CONCLUSION

Combining boost converter operating in DCM and ZVS-CV topology, we proposed a new ZVS-CV topology with PFC function. The new circuit is much simpler, only one diode and one inductor are added compared with conventional ZVS-CV topology. Simulation and experiment results show that good input line current waveform and low switch losses can be achieved and that the design principles are reliable.

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