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SIMULATION OF A NOVEL ZERO VOLTAGE TRANSITION TECHNIQUE BASED ON BOOST POWER FACTOR CORRECTION CONVERTER WITH EMI FILTER

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ABSTRACT

A novel Zero Voltage Transition (ZVT) technique based closed loop control of Boost Power Factor Correction (PFC) converter with Electro Magnetic Interference (EMI) Filter is presented in this paper. It operates at a fixed frequency while achieving zero voltage turn-on of the main switch and zero current turn-off of the boost diode. This is accomplished by employing resonant operation only during switch transitions. During the rest of the cycle, the resonant network is essentially removed from the circuit and converter operation is identical to its non-resonant counterpart. The principle of operation and simulation results of proposed converter is presented in this paper. The power factor is improved to near 0.99 using the proposed converter.

Keywords: zero voltage transition, power factor correction, electro magnetic interference, common mode, differential mode.

INTRODUCTION

The demand for power, which is increased tremendously over the last few decades, has forced the power engineers to establish reliable network in order to supply “quality” power to the consumers. Power factor, which is defined as the cosine of the phase angle between the voltage and current signals, plays a key role in delivering quality power to the consumers [1].

Over the years lot of research has been carried out for the control of the power factor. This research got a tremendous boost with the strides made in the miniaturization of the electronic industry. The component of input current normal to voltage across the load resistance wastes power in the resistance of the source generator. In power supplies with a capacitor filter across the input bridge rectifier, the input line current consists of very narrow spikes with the fast rise and fall time. These current spikes have a high rms value, waste power and give rise to RFI/EMI problems. Power supplies with such input line currents have poor “power factor”. Power Factor Correction seeks to eliminate such line current spikes and force input current to be sinusoidal, in phase with input voltage and to generate a fairly well regulated DC output voltage somewhat greater than the peak of the incoming sine wave [2,3].

Generally EMI problems arise due to the sudden changes in voltage (dv/dt) or current (di/dt) levels in a waveform. In diode rectifier, the line current can be pulse of short duration and the diode recovery current pulse can generate transient voltage spikes in the line inductance. A conductor carrying dv/dt wave acts like an antenna and sensitive signal circuit and appear as noise. The EMI problems create communication line interference with sensitive signal electronic circuits.

Basic boost power factor correction converter

Boost converters can be operated in either the discontinuous or continuous mode. But the continuous-mode boost topology is far better suited to yield relatively smooth, ripple-free half sinusoids of input line current in this application. This can be seen from Figure 1, which shows a continuous-mode boost converter fed from a constant DC input voltage. The continuous-mode boost topology differs significantly from the discontinuous mode.

In the discontinuous mode, the inductor L_1 is made small to yield a steep ramp ($di/dt = V_{IN}/L_1$) of input current to Q_1. When Q_1 turns off, all the current or energy stored in L_1 is transferred via D_1 to the load. Since L_1 is small, the downward ramp of current through D_1 [$di/dt = (V_0-V_{IN})/L_1$] is also steep and D_1 current falls to zero before the next Q_1 turn-on. The input line current then, which is the sum of the Q_1 current when it is ON and the D_1 current when Q_1 is OFF, is not at all constant over one complete switching cycle. It consists of steep up and down ramps with zero current gaps between the end of a turnoff and the next turn-on.

But in the continuous-mode of Figure-1, the inductor L_1 is made significantly larger. Then the Q_1 current (Figure-1c) has the shape of a large step of current with a slow upward ramp on it, and the D_1 current has the shape of a large step with a slow downward ramp. And importantly, there is no gap of zero current between the end of a turnoff and the next turn-on. Input line current (Figure-1e) is now the sum of the I_{Q1} and I_{D1} currents and if the ramps are made small by using a large L_1, the line input current over one switching cycle is then a constant I_{av} with very small peak-to-peak ripple of ΔI. The input power is $V_{IN}I_{av}$.

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Now for an Ac input, such a continuous-mode boost converter is used after the input bridge rectifier output. At any point on the half sinusoid input voltage, the Q_1 ON time will be forced by a PWM control chip to boost that instantaneous voltage to the desired DC output voltage. A DC voltage error amplifier, a DC reference voltage, and a pulse with modulator in the control chip modulate the Q_1 ON time in a negative feedback loop, to yield a constant DC output voltage throughout the half sinusoidal input voltage. The instantaneous input line current will be sensed by a sensing resistor R_S and will be proportional to the instantaneous voltage throughout the half sinusoid. During any one ON time, current flows through L_1, Q_1 and R_S back to the negative end of the bridge and during the following OFF time it flows through L_1, D_1, R_0 and C_0 in parallel and R_S back to the negative end of the bridge. By making L_1 large, the peak-to-peak ripple current throughout each switching cycle is kept small. Depending on switching speed of Q_1, there may be very narrow spikes on the half sinusoids of current monitored in R_S. If present, these may cause an RFI problem. But a very small capacitor (in the vicinity of 1.0mF) across R_S easily eliminates them.

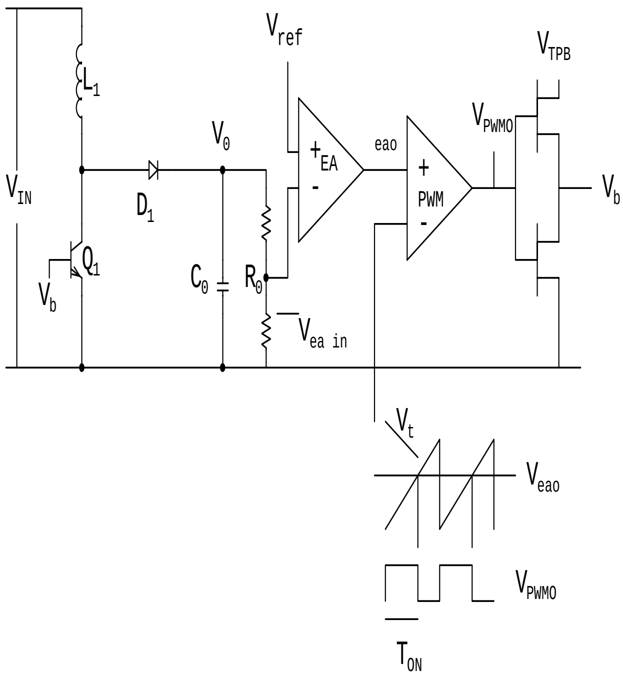

Figure-1a

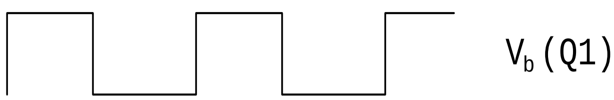

Figure-1b

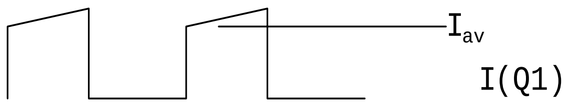

Figure-1c

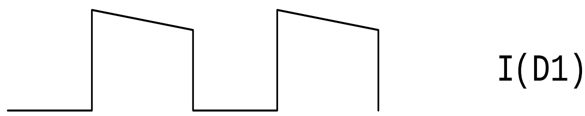

Figure-1d

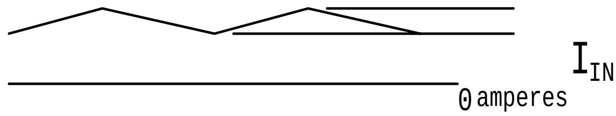

Figure-1e

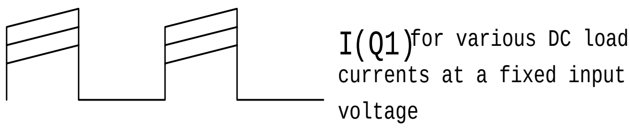

Figure-1f

Figure-1. Continuous conduction mode Boost Converter and wave forms of Q_1 and D_1 for various DC load currents at a fixed DC input voltage.

Zero Voltage Transition (ZVT) technique

The power stage of proposed PFC converter with ZVT technique based boost topology is shown in Figure-2 and the ZVT timing diagram is shown in Figure-3. The capacitive turn-on losses can be theoretically eliminated and the overlap of non-negligible active switch voltage and current can be avoided at turn-on, by using the Zero Voltage Switching – ZVS technique. Basically, this technique consists of forcing to zero the active switch voltage, prior to its turn-on, by creating a resonance between an inductor and a capacitor. The inductor also limits the rate of variation of the diode current, so losses due to the reverse recovery are reduced as well [4].

However, better characteristics are obtained in Zero Voltage Transition – ZVT topologies, at the expense of increased complexity. Here, to achieve ZVS, switch voltage and current waveforms are changed only during commutation intervals, the behavior of the ZVT converter being otherwise identical to that of the hard-switching converter.

In converter topologies having only one active switch, the ZVT technique is implemented with an auxiliary circuit, which consists of an additional active switch, an auxiliary inductor, for the resonant process that discharges the drain-source capacitance of the switch and for limiting the rate of change of the diode current at turn-off, as well as a few other passive components [5,6].

The auxiliary switch is turned on before turning on the main active switch. This initiates a resonant process, which creates zero voltage switching conditions for the main active switch. The time intervals where the auxiliary circuit is active are very short when compared to the switching period; hence, except for the commutation intervals, the waveforms of the ZVT Boost converters are the same as those of the hard-switching Boost converter [7].

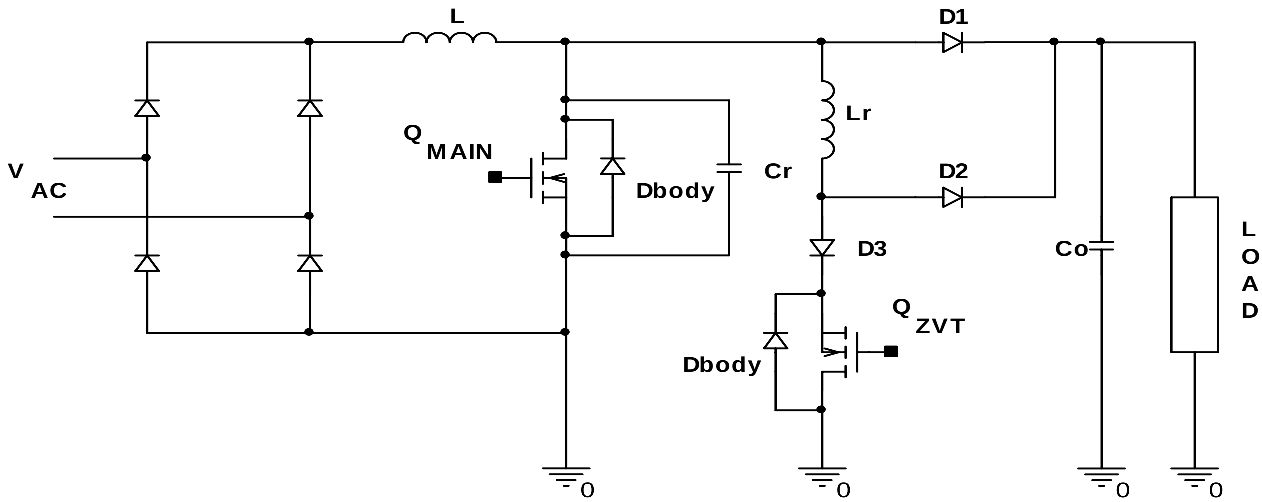

Figure-2. Power circuit of ZVT based Boost PFC Converter.

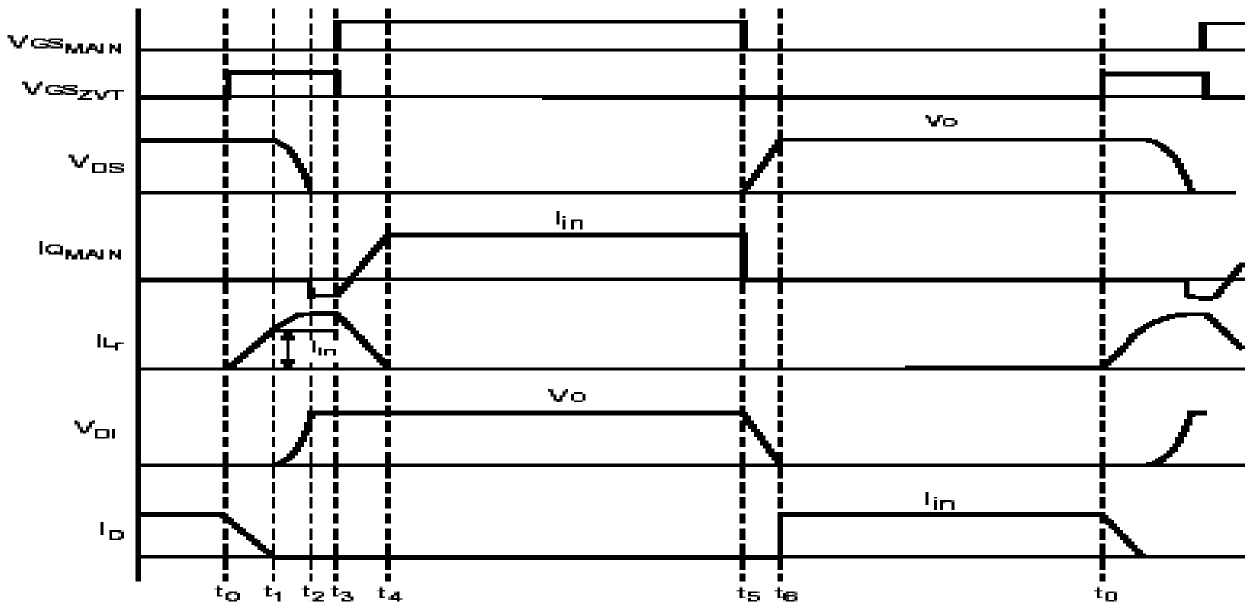

Figure-3. Timing diagram of ZVT technique.

The design specifications for the proposed ZVT based Boost PFC Converter are:

AC input Voltage = V_S = 170 – 250 Volts (rms)
DC output Voltage = V_0 = 400 V
Output Power = P_{out} = 1000 W
Switching Frequency = F_s = 250 KHz
Efficiency = η = 95%

The designed values of different components in the converter circuit are:

L = 500µH; C_0 = 1600µF; L_r = 8µH; C_r = 470pF

Electro Magnetic Interference (EMI) filter

The Electro Magnetic Interference can be transmitted in two forms: radiation and conduction. The switching converters supplied by the power lines generate conducted noise into the power lines that is usually several orders of magnitude higher than the radiated noise into free space. Metal cabinets used for housing power converters reduce the radiated component of the electromagnetic interference. Conducted noise consists of two categories commonly known as the differential mode and the common mode.

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The differential mode noise is a current or a voltage measured between the lines of the source that is line-to-line voltage. The common mode noise is a voltage or a current measured between the power lines and ground that is line-to-ground voltage [8]. An EMI filter is needed to reduce the differential mode and common mode noises. The EMI Filter for Boost PFC converter is shown in Figure-4.

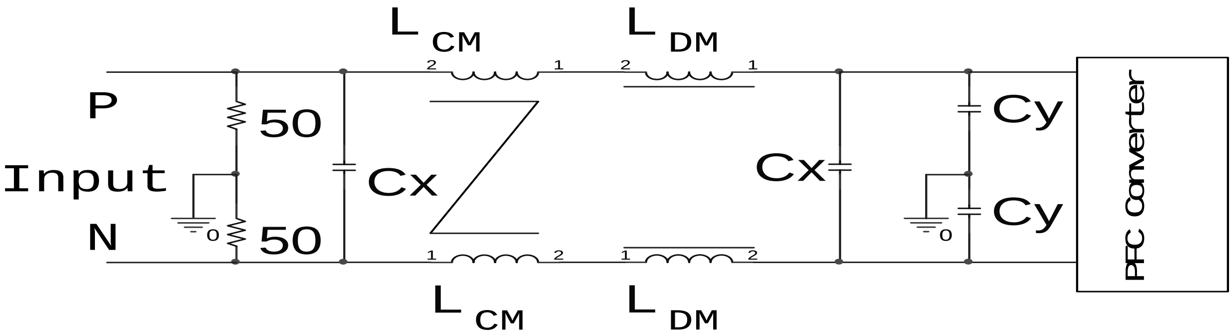

Figure-4. EMI Filter for Boost PFC Converter.

For CM Noise,

$f_{R,CM} = 1/(2\pi\sqrt{(2Cy*L_{CM})})$ - (1)

$L_{leakage}$ = 0.5% to 2% of L_{CM} - (2)

For DM Noise,

$f_{R,DM} = 1/(2\pi\sqrt{(2L_D C_X)})$ - (3)

$L_{DM} = (L_D - L_{leakage}) / 2$ - (4)

The PFC converter has the predicted noise level and EMI which includes total noise, common mode and differential mode noises. In general, the corner frequencies of EMI noises in the PFC circuits are 28 KHz for CM noise and20.5 KHz for DM noise. The designed values are L_{CM} is 4.9mH and L_{DM} is 40µH.

RESULTS

Figure-5 shows the input voltage waveform without EMI Filter. Figure-6 shows the input current waveform without EMI Filter. In this Figure, there is more noise and more spikes. Figure-7 shows the input voltage waveform with EMI Filter. Figure-8 shows the input current waveform with EMI filter. Here, the noise and spikes are reduced because of Filter. Here, the power factor is around 0.99 and the noise and spikes are also reduced.

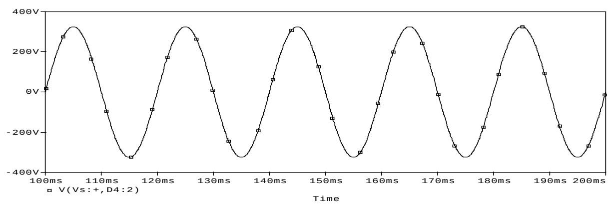

Figure-5. Input Voltage waveform without EMI Filter.

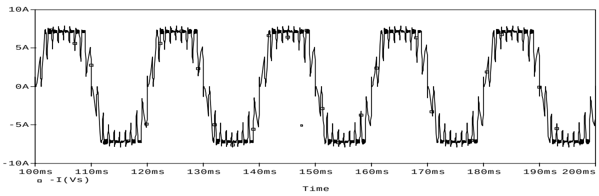

Figure-6. Input Current waveform without EMI Filter.

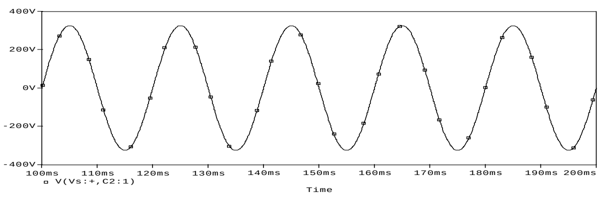

Figure-7. Input Voltage waveform with EMI Filter.

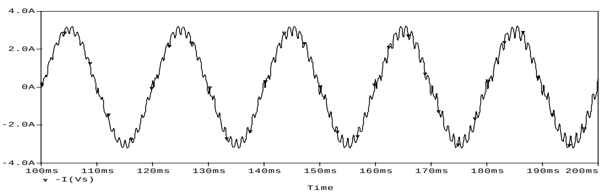

Figure-8. Input Current waveform with EMI Filter.

CONCLUSION

A Boost Power Factor Correction (PFC) Converter with EMI Filter employing Zero Voltage Transition (ZVT) technique is proposed. The proposed converter is simulated and the simulation results are presented in this paper. Power factor is improved upto 0.99 (lag) without compromising the efficiency because of the active snubber.

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