

AVERAGE CURRENT CONTROL MODE BOOST CONVERTER FOR THE TUNING OF TOTAL HARMONIC DISTORTION & POWER FACTOR CORRECTION USING PSIM

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Abstract: The aim of this paper is to investigate the Total Harmonic Distortion (THD) and power factor (PF) correction of Boost Converter under an average current-mode control technique. Boost converter can perform this type of active power-factor correction in many discontinues/continuous modes. Boost converter is usually used due to its ease of implementation and good performance. Comparative evaluation using average current control method is used in the ac-dc converter to improve total harmonic distortion (THD). Average current measurement provides the input current with a high degree of accuracy. This is important in high power factor pre-regulators, enabling less than 5% total harmonic distortion (THD) to be achieved with a relatively small inductor. Average current mode control technique works well even when the mode boundary is crossed into the discontinuous mode at low current levels. The outer voltage control loop is oblivious to this mode change. Simulation and hardware results of simple bridge rectifier, Boost Converter open loop and Boost Converter close loop using average current mode control are presented in this paper. In order to show the system stability, a step response is applied at that load. All the converters are simulated by Power Simulation (PSIM) Software and experimental results are presented to show the response of the proposed system. Both simulation and experimental results verify the validity of the proposed system.

Keywords: PSIM, Average Current mode Control, Power Factor Correction, Boost Converter, Total Harmonic Distortion (THD)

1. Introduction

AC-DC converters are used in adjustable speed drives, SMPS, UPS etc. More or less all home appliances and Power Electronics systems use AC power supply which is converted to DC supply using diode rectifier. The non-linear nature of diode rectifier causes substantial line current harmonic generation; hence, they lower power quality, increases losses, which may also cause failure of some crucial medical equipment and so on. Therefore, harmonic reduction circuits are incorporated in Power Electronics system [1].

Bulky and expensive inductor and capacitor have been employed previously [2] but they effectively eliminated

certain harmonic. Active power line conditioners (APLC) used for harmonic reduction are generally hard switched, which result in low efficiency, high component stress etc. Soft switched resonant converter are usually operated in variable frequency mode and thus components are required to be designed at lowest operating frequency. Active clamped technique, which is also called zero voltage switching (ZVS), is used in various converters. Boost converter topology in continuous conduction mode (CCM) has been used in medium power AC to DC converter, because it gives near unity power factor at AC input [3, 4].

Power-factor-correction (PFC) converters are widely used in power supplies for pre-regulation of power factor. In general, any type of switching converter can be suitable for PFC purpose [5–7]. But in practical the Boost converter has been the ideal choice when the factor of current stress and efficiency are taking into account. As a typical nonlinear circuit system, PFC Boost converters are found to display fast-scale instability, such as bifurcation and chaos operation, over the time of line cycle. These complex behaviors indicating instability should be avoided from the viewpoint of classical design methodologies, which can be realized by the changing of circuit parameters, or enclosing the accessional control method when the circuit parameters are fixed. The basic practical requirement for power supplies is to regulate output voltage. In addition, this requirement has to be combined with that of power-factor-correction (PFC) in the design of most practical power supplies. The power factor is defined as the ratio of the active power to the apparent power, which represents a useful measure of the overall quality level of satisfaction of power supplies and systems in areas of performance such as harmonic distortion and electromagnetic interference. In general, any type of switching converters can be chosen as a PFC stage. In practice, while considering the current stress and efficiency, the boost converter has been a favorable and popular choice. The discontinuous conduction mode

of operation has the obvious advantage of simplicity since no additional control is required [8].

In a conventional switching power supply using a buck derived technique, an inductor is used in the output stage. Current control mode is actually output current control, resulting in many performance advantages [9, 10]. In contrast, in a high power factor pre-regulator using the boost technique, the inductor is used in the input stage. Current control mode then controls input current, allowing it to be easily followed to the desired sinusoidal wave shape. In high power factor boost pre-regulators the peak/average error is very serious because it causes distortion of the input current waveform. While the peak current follows the desired sine wave current, the average current does not. The peak/average error becomes much worse at lower current levels, especially when the inductor current becomes discontinuous as the sine wave approaches zero in every half cycle. To achieve low distortion, the peak/average error must be small. This requires use of a large inductor to make the ripple current small. The resulting shallow inductor current ramp makes the already poor noise immunity much worse. The average current mode method can be used to sense and control the current in any circuit branch. Hence it can control input current accurately with buck and fly back techniques, and can control output current with boost and fly back techniques [11, 12].

2. System design

Average current control Boost Converter for the improvement of power factor and total harmonic distortion has been used in this work. The boost converter is a highly efficient step-up DC/DC switching converter. The converter uses a transistor switch, typically a MOSFET, to pulse width modulate the voltage into an inductor. Rectangular pulses of voltage into an inductor result in a triangular current waveform. For this work it is also assumed that the converter is used in the continuous mode, which implies that the inductor's current never goes to zero.

Mathematical notations and formulas used in Boost Converter are shown below in table 1.

The boost converter has two conduction states, continuous conduction mode and discontinuous conduction mode. The block diagram of boost converter is shown in figure (1).

Table 1
Basic Formulas of Boost Converter

Components/ Parameters	Formulas
Peak inductor current	i_{pk}
Min inductor current	i_o
Ripple Current	$\Delta i = (i_{pk} - i_o)$
Ripple Current Ratio to Average Current	$r = \Delta i / i_{ave}$
Off Duty Cycle	$1 - D = T_{off} / T$
Switch Off Time	$T_{off} = (1 - D) / f$
Average and Load Current	$i_{ave} = \Delta i / 2 = i_{load}$
RMS Current for a Triangular Wave	$i_{rms} = \sqrt{i_o^2 + (\Delta i^2) / 3}$

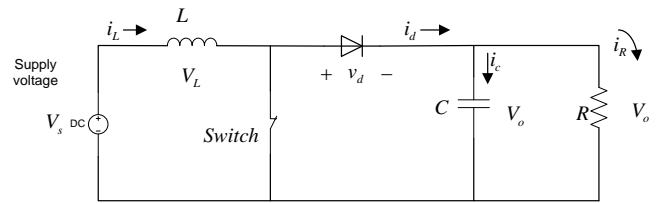


Fig. 1 Basic Diagram of Boost Converter

The average current control mode method is based on the idea of feedback control of input current. Two PI controllers have been used to stabilize the system. Satisfactory results are obtained after using the average current control method.

3. Simulation & results using PSIM software

PSIM software has been used for simulation. Initially a bridge rectifier was designed and its THD was calculated. It was found excellent with respect to requirements simply because no passive element is employed in circuit. Then the bridge rectifier using boost converter was designed. The results showed higher THD which was not desirable. In order to improve the THD of boost converter average control method was incorporated into the design.

The circuit diagram of the systems designed in PSIM software is explained below.

A. Simple Bridge Rectifier

The circuit diagram of simple bridge rectifier is shown in figure (2).

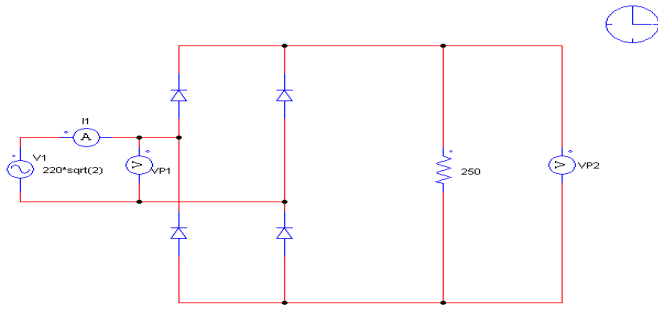


Fig. 2 Bridge Rectifier

The results are given below

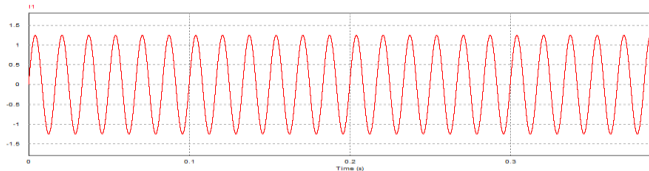


Fig. 3 Input Current

The THD of bridge rectifier is shown below in figure (4). It shows that if the circuit is simple BRIDGE RECTIFIER then its THD will be very low, because no passive element is used in this circuit.

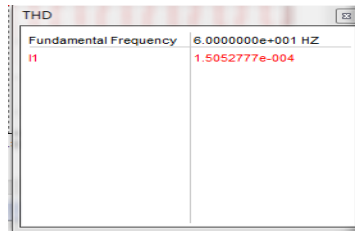


Fig. 4 Total Harmonic Distortion of Simple Bridge

B. Bridge Rectifier Using Boost Converter

The circuit diagram of Boost Converter is shown in figure (5).

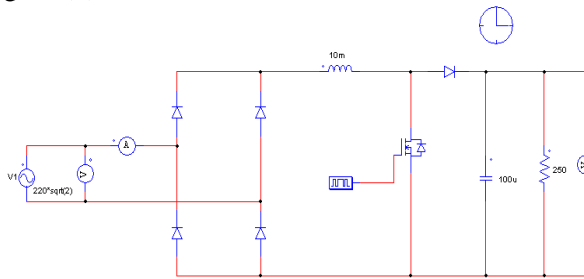


Fig. 5 Boost Converter

The results of input current are shown in figure (6).

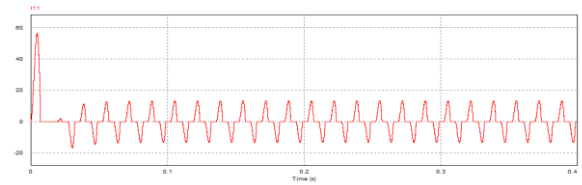


Fig. 6 Input Current of Boost Converter

The result clearly shows presence of lot of ripples in the waveform indicating a very high THD. The THD data is shown below in figure (7).

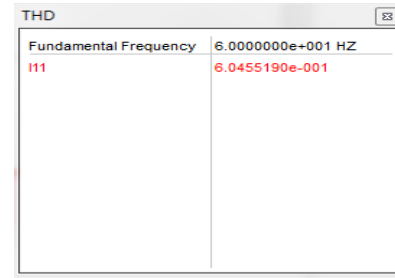


Fig. 7 Total Harmonic Distortion of Boost Converter

It indicates that THD is more than 60% that needs to be reduced to around 5%. To achieve the desired goal an average current controller using boost converter is designed.

C. Average Current Control Method using Boost Converter

The circuit diagram of Average Current Control method using Boost Converter is shown below in figure (8). PSIM software is used for the design of circuit. The input and out put voltages are 220 V_{RMS} and 400V respectively while value of each component is shown in table II. Duty cycle of 0.4 is selected whereas values of PI controller are chosen according to the circuit requirements. Table II shows the basic components of the circuit diagram.

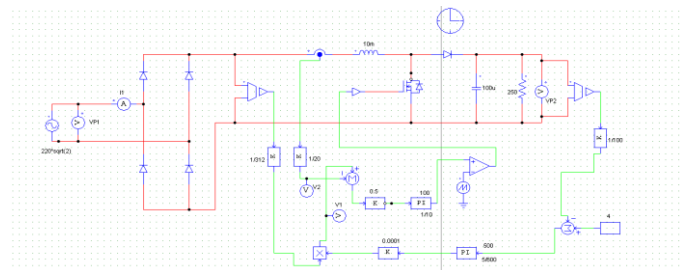


Fig. 8 Average Current Control Method

Table 2
Parameters used in Simulation

Components/ Parameters	Values
Input Voltage	220V _{RMS}
Duty cycle	0.4
Inductor	10 mH
Capacitor	100 uF
Resistor	250 Ω
Switching Frequency	100 KHz
Reference Voltage	400 V

The simulation results are shown below. The input voltage is shown in figure (9), which is 220V_{RMS}.

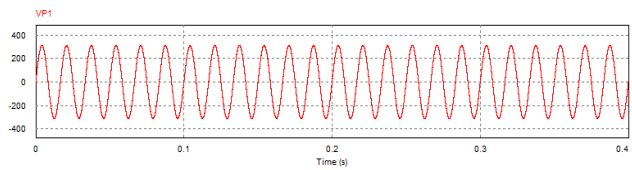


Fig. 9 Input Voltage

Due to boost converter circuit output is higher than the input. The output voltage is 400V DC. The output waveform is shown in figure (10).

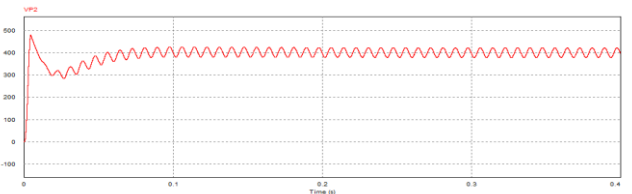


Fig. 10 Output Voltage

The Input Current is shown below in figure (11)

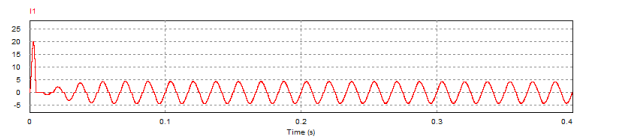


Fig. 11 Input Current

The waveform shows no presence of ripples, hinting towards a good THD value. The THD of input current is shown below in figure (12).

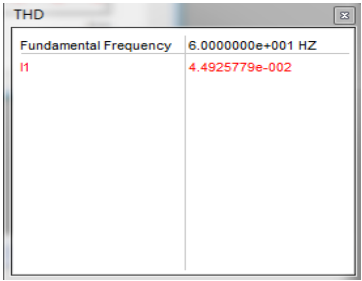


Fig. 12 Total Harmonic Distortion

It shows that THD is almost 4.5%, which is considered as a good THD value. So results are improved by applying the average current control method to the Boost Converter.

In the average current control method, a feedback circuit diagram has been used which can be seen in figure (8). In the feedback circuit diagram, the comparison analysis of Inductor Current and Reference Current is evaluated which is shown in figure (13).

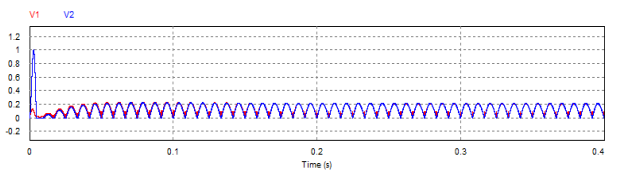


Fig. 13 Comparison of Inductor Current and Reference Current

The figure shows that both waveforms are identical with same periodic cycle.

D. Average Current Control Method Boost Converter using Variable Load

The circuit diagram is shown in Figure (14), which shows the Average Current Control Method using variable load. Step size of 0.2 sec is selected while parallel resistance of 500 ohm is selected. It is clear from figure (15) that after 0.2 sec step output voltage, input current and input voltage goes down to 0.2 and then restore to the original position. The Block diagram of the circuit is shown in figure (14).

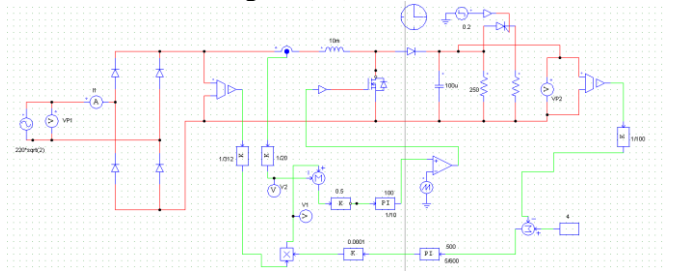


Fig. 14 Average Current Control Method with Variable Load

The output Voltage is shown in Figure (15).

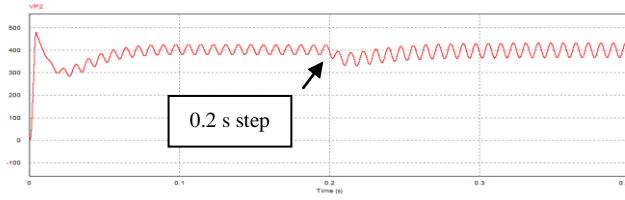


Fig. 15 Output Voltage with Variable Load

The input current shown below in figure (16) shows the change at 0.2 sec.

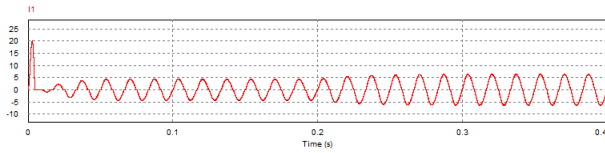


Fig. 16 Input Current with Variable Load

After applying the variable load, the THD is shown in figure (17), which is around 4% and considered to be reasonably good.

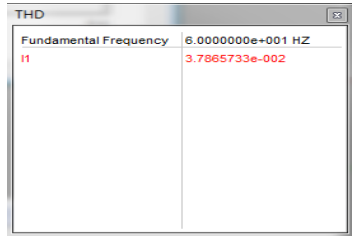


Fig. 17 Total Harmonics Distortion with Variable Load

The comparison of Inductor Current and Reference Current is shown below in Figure (18).

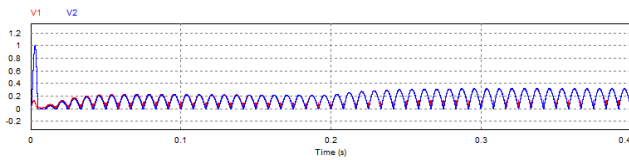


Fig. 18 Comparison of Inductor Current and Reference Current with Variable Load

It is clear that both have identical waveforms.

4. Experimental results

Average current control boost converter was implemented on hardware and satisfactory results were obtained. ADLINK's data acquisition card USB-1902 was used to get output waveforms on PC, that are drawn using MATLAB and are shown below.

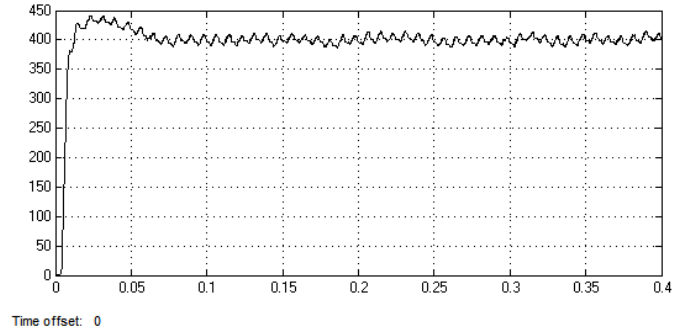


Fig. 19 Output Voltage

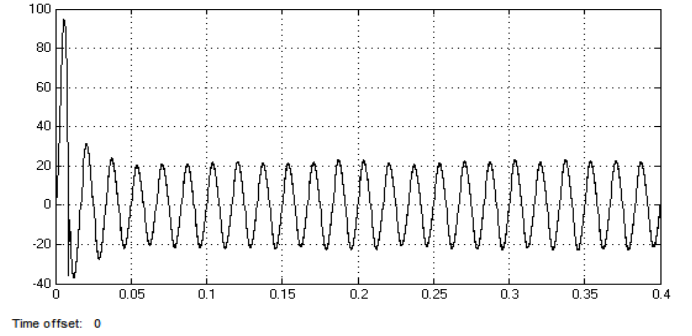


Fig. 20 Input Current

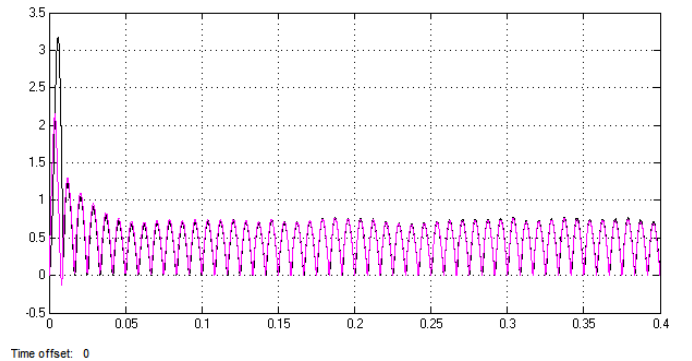


Fig. 21 Comparison of Inductor Current and Reference Current

5. Conclusion

THD and PF correction of Boost Converter using average current control method is presented in this paper. PSIM software has been used for circuit design, measurement of THD and PF. Initially results of open loop uncontrolled rectifier are shown, followed by description of the average current control method. The average current control method resulted in enhancement of the performance and improvement of the results (THD and PF). In the results of uncontrolled rectifier, it can be seen that harmonics are very high. Closed loop controlled rectification is then used for harmonics reduction and PI controllers were tuned to get the

satisfactory results. The comparison of Inductor current and the reference current is also presented which is essentially the comparison of rectified scaled voltage and the output DC voltage. Furthermore the transient and steady state analysis of average current control method is also given, which also shows satisfactory results. In the end an improved THD value of 4.45% is achieved using simulation. Experimental results also validate the simulation results.

6. Acknowledgment

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