Singaporean Journal of Scientific Research(SJSR)
Journal of Selected Areas in Microelectronics (JSAM)
Vol.8.No.1 2016 Pp.27-34
available at :www.iaaet.org/sjsr
Paper Received : 08-03-2016
Paper Accepted: 19-04-2016
Paper Reviewed by: 1.Prof. Cheng Yu 2. Dr.M. Akshay Kumar
Editor : Dr. Chu Lio

DYNAMIC ANALYSIS OF BOOST CONVERTER FOR POWER FACTOR IMPROVEMENT AND THD REDUCTION

A. Dhivya
PG Scholar
Department of Electrical and Electronics Engineering
Government College of Engineering, Salem ,Tamilnadu, India

D. Murali
Assistant Professor
Department of Electrical and Electronics Engineering Government College of Engineering, Salem
Tamilnadu, India

ABSTRACT

This paper proposes an average current mode control technique applied to boost converter for Power Factor (PF) improvement and Total Harmonic Reduction (THD). In this technique PI control has been used to make input current waveform to achieve the shape of input voltage. This boost converter topology works well when the boundary mode is crossed into many continuous conduction (CCM) and discontinuous conduction modes (DCM). The simulation of both open and closed loop control circuit has been performed in Power Simulation (PSIM) for a duty cycle of 0.6.Hence the waveforms of input current show the improvement of PF and THD reduction.

Index Terms—*Average Current Mode Control, Boost Converter, CCM,DCM, PF, PSIM,THD.*

I. Introduction

Single phase diode rectifiers are the mainly used circuits for practical application whenever the input is the ac supply (e.g.: computers, communications, air conditioning etc). These conventional converters perform by rectifying the input ac line voltage and filtering it with large capacitor. The filter capacitor lessens the ripple available in the output voltage but provides distortion in the input current which lowers the power factor. Various power factor correction (PFC) strategies are implemented to encounter these power quality issues out of which the boost converter topology has been widely used in various ac/dc and dc/dc applications. In, the front end of today's ac/dc power supplies with power-factor correction (PFC) is practically implemented with boost topology [2-4]. The low power factor and high pulsating current from the AC mains are the main drawbacks of the diode rectifier and phase controlled rectifier. These circuits create severe power pollution in the transmission or distribution system. The power pollutants such as reactive power and current harmonics results in line voltage distortion, heating of core of transformer and electrical machines and increasing losses in the transmission and distribution line.

The boost PFC continuous conduction mode (CCM) is the preferred choice for medium and high power utility. This is mainly because the continuous tendency of the boost converter's input current results in low conducted electromagnetic interference (EMI) when compared]to other active PFC particularly buck–boost and buck converters. The active rectifier of the AC/DC/AC converter is adopted to handle the DC bus voltage for motor drive. The non-linear load generates a pulsating current with large current.

An active power filter is employed to compensate the reactive power and current harmonics drawn from the non-linear load and the AC/DC/AC converter. This strategy needs an additional inverter and measurement of both the nonlinear load currents and the compensated currents. The cost of implementation of this strategy is very high. To incorporate the functionality of power factor adjustment, active power filter as well as AC/DC converter, this new power factor modification means employing PFC Boost converter is featured to operate all at the same time as an active power filter to deliver compensated currents which happen to be on par with the harmonic currents excitation resulting in saturation. A hysteresis current control is implemented to monitor the necessary line current control. In this particular strategy PFC boost converter enable you to prevent the harmonic current created by the diode rectifier.

The PFC boost converter delivers the required harmonic current generated by the non-linear load. Hence the total design leads a nearly sinusoidal current with the better power factor [5-7]. In a traditional switching power supply employing a buck derived technique, an inductor is used in the output stage. Current control mode is indeed output current control, resulting in many performance benefits.

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, offering it to be easily adhered to the expected sinusoidal wave shape. In high power factor boost pre-regulators the peak/average error is very dangerous since it results in distortion of the input current waveform. Even though the peak current follows the desired sine wave current, the average current does not. The peak/average error turns into much more severe at lower current levels, notably when the inductor current happens to be discontinuous as the sine wave approaches zero in every half cycle[8].

To attain low distortion, the peak/average error must be minimal. This will involve use of a large inductor to acquire the ripple current small. The resulting shallow inductor current ramp tends to make 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 [9,10].

This paper primarily comprises of simulation of simple power electronic rectifier circuits and the technical analysis of the current and voltage waveforms. It begins with fundamental circuits and transforms to complex circuits by employing advanced methods possibly active PFC and their successive impact on the current and voltage waveforms seeking best outcomes especially working for the purpose of improving upon the input current waveform i.e. which makes it sinusoidal by tuning the circuits. Here for average current mode control, PI controllers are employed. All the simulation is carried out by PSIM.

II. POWER FACTOR WITH DIFFERENT LOADS

Power factor is defined as the ratio of the real power to the apparent power. In other words, it can also be termed as the cosine of the angle between the voltage and current. The current lags behind the voltage if the load is inductive in nature and leads if the load is capacitive in nature.

Linear System

Whenever a sinusoidal voltage is applied to some kind of load, the current taken by the load is proportional to the voltage and is a follower of the voltage waveform. These kinds of loads are categorized as linear loads .Instances of linear loads are resistive heaters, incandescent lamps, and constant speed induction and synchronous motors.

Non-Linear System

On the other hand, certain loads result in the current to change disproportionately with the voltage through every half cycle. These loads are categorized as non-linear loads
Instances of non-linear loads are battery chargers, electronic ballasts, variable frequency drives, and switching mode power supplies. For sinusoidal voltage and non-sinusoidal current P.F can be expressed as

$$PF = \frac{V_{rms} \times I1_{rms}}{V_{rms} \times I_{rms}} \times \cos\theta \qquad (1)$$

$$PF = \frac{I1_{rms}}{I_{rms}} \times \cos\theta = K_d \times K_p \qquad (2)$$

Where, cosθ is the displacement factor of the voltage and current. Kp is the purity factor or the distortion factor.

III. EFFECTS OF HARMONICS ON POWER QUALITY

The harmonics can turn down power quality and influence on system functionality in numerous ways. Since presence of harmonics declaims the transmission efficiency as well as produces thermal problems, both conductor and iron loss are increased. In 3-Φ system, neutral conductor becomes unprotected due to odd harmonics. Huge current flows through the ground conductor of system with four wire 3-Φ when odd number of n-current is present in harmonics.

Eventually, harmonics might as well cause other problems such as electromagnetic interference to interrupt communication, degrading the reliability of electrical equipment, increasing defective product ratio, insulation failure, audible noise, etc.

IV. TYPES OF POWER FACTOR CORRECTION

Passive PFC

A capacitive or inductive filter is added at the AC input to improve the PF is referred to as passive power factor correction. It may be affected when environmental vibration occurs.

Active PFC

The method of improving PF by adding active power electronic circuits with feedback control circuit to shape the current waveform is referred to as active power factor correction

V. BOOST CONVERTER

To avoid the issue of pulsating input current PFC strategies are employed. Better outcome can be acquired by making use of active PFC strategies based on switch mode power converters. The boost topology is indeed widely recognized in comparison with some other PFC methods. The circuit diagram of a boost converter is presented in Figure. 1

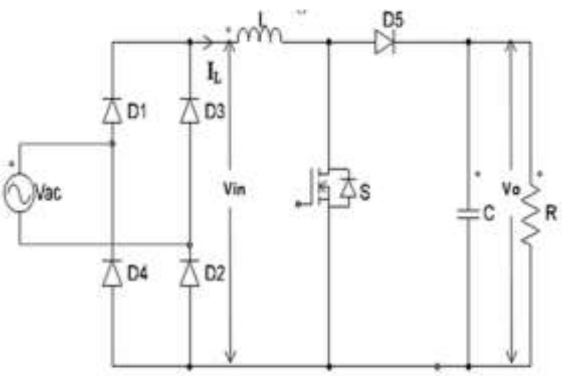

Fig.1 Boost converter

When the switch S is on the current I_L increases and passes through inductor L. When switch S is off the current I_L decreases and passes through L, diode D5, C, and R. The current I_L falls until switch S is switched on all over again.

So when switch S is on:

$$\frac{\Delta i_L}{\Delta t} = \frac{V_{in}}{L} \quad (3)$$

Again when the switch is off:

$$V_{in} - V_o = L\frac{di_L}{dt} \quad (4)$$

Here V_{in} is the rectified input voltage and V_o is the output voltage. Thus the boost converter gets continuous input current. This input current could be regulated to adhere to a sinusoidal reference with the use of average current mode control technique

VI. Average Current Mode Control

A. System specifications

Average current control Boost Converter for the |enhancement of power factor and also total harmonic distortion has been used in this particular work. The boost converter is a highly effective boost DC/DC switching converter. The converter employs a transistor switch, generally a MOSFET, to pulse width modulate the voltage into an inductor. Rectangular pulses of voltage into an inductor lead to a triangular current waveform. For this purpose work it is also presumed that the converter can be used in the continuous mode, which means that that the inductor's current in no way goes to zero.

Boost converter possesses two conduction states, continuous conduction mode, and discontinuous conduction mode. The block diagram of boost converter is presented in Figure. 2

The average current mode control technique is feedback control for current. It includes two PI controllers to balance the system. After applying this average current control method, the outcomes are pretty good.

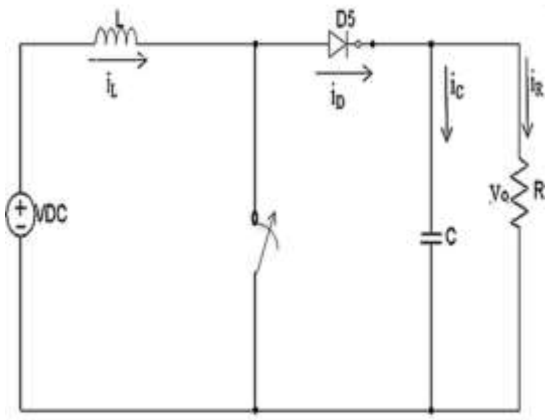

Fig .2 Basic Diagram of Boost Converter

The average current mode control the control circuit contains two parts. They are:

- Feed forward/current control loop
- Feedback /voltage control loop

B. Current Control Loop

The objective of the current control loop is to always drive the current waveform to stick to the shape of the voltage waveform. To ensure that the current to go along with the voltage, the internal current amplifier needs to be created to seize enough of the harmonics of the output voltage by means of external capacitors and resistors.

Soon after designing this it makes use of information from the gain modulator to regulate the PWM control that handles whether or not the power MOSFET is turned on or off. The core of the PFC controller is the gain modulator. The gain modulator provides two inputs and one output. The left input to the gain modulator block is called the inductor current (I_L). The reference current is the input current that is proportional to the input full-wave-rectified voltage. The additional input, situated at the lower of the gain modulator, is from the voltage error amplifier. The error amplifier obtains the output voltage after the boost diode and compares it to a reference voltage. The error amplifier may have a small bandwidth in order not to allow any sudden variations in the output or ripple erratically have an impact on the output of the error amplifier. The gain modulator multiplies or is the product of the reference current and the error voltage from the error amplifier

C. Voltage Control Loop

The gain modulator and the voltage control loop act together to sample the input current and output voltage, respectively. Both of these measurements are taken out after which they would compared against one another to evaluate if a gain needs to be put on to the input of the current control. This final decision is then compared against a sample of the output current to find out the duty cycle of the PWM.

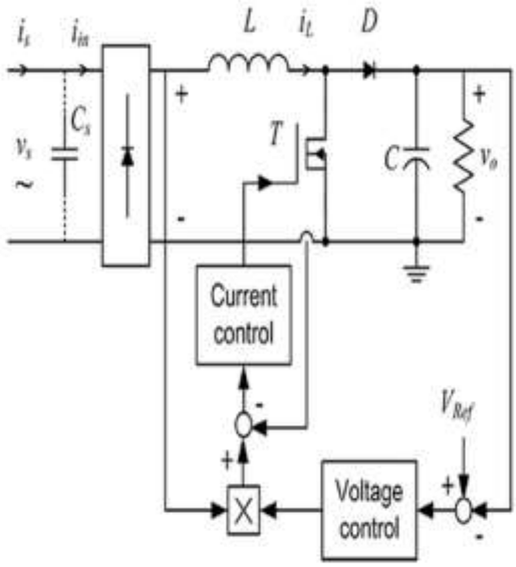

Fig.3. Average current mode control

Once developing this it makes use of details from the gain modulator to regulate the PWM control that controls whether the power MOSFET is turned on or perhaps off. The center of the PFC controller is the gain modulator. The gain modulator consists of two inputs and one output. The left input to the gain modulator block is called the inductor current (I_L). The reference current is the input current that is definitely proportional to the input full-wave rectified voltage. The other input, located at the lower of the gain modulator, is from the voltage error amplifier. The error amplifier gets the output voltage after the boost diode as well as compares it to a reference voltage. The error amplifier may have a small bandwidth in order not to permit any sudden modifications in the output or ripple erratically influence the outcome of the error amplifier. The gain modulator multiplies or makes it the product of the reference current and the error voltage from the error amplifier.

VII. Simulation Results And Discussions

A. Simple Bridge Rectifier

The circuit diagram of the simple bridge rectifier is presented in Figure. 4

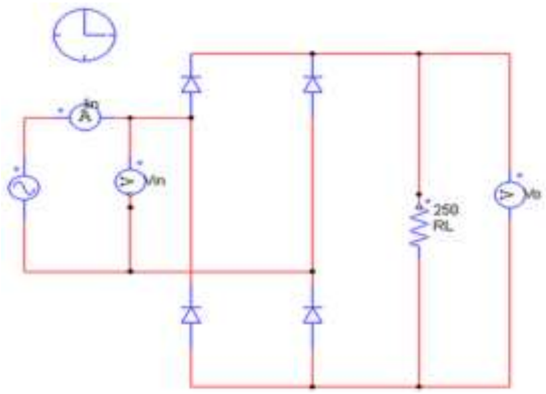

Fig.4 Simulation diagram of simple Bridge Rectifier

The results are as given below

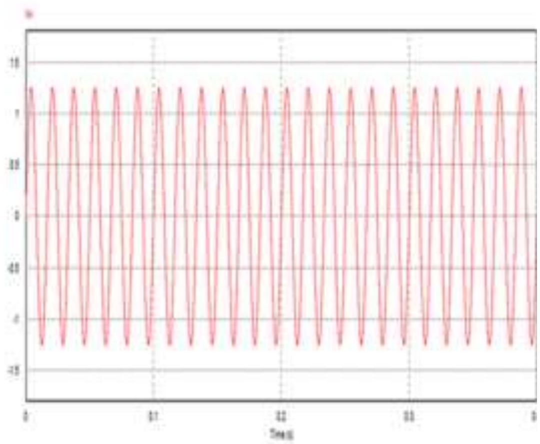

Fig.5 Input Current waveform of Simple bridge rectifier

B. *Bridge Rectifier Using Boost Converter*

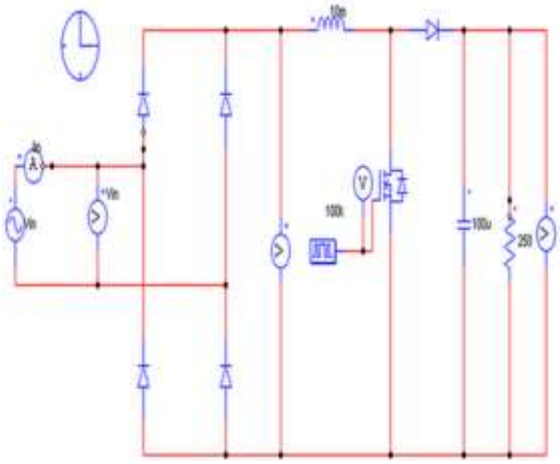

Fig.6 Simulation diagram of Bridge rectifier using Boost Converter

The waveform of input current is given in Figure.7

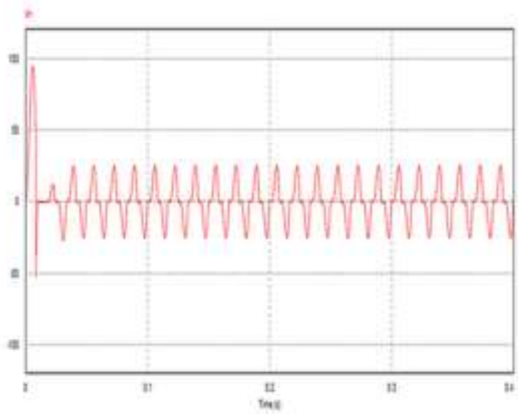

Fig.7 Input Current waveform of Boost Converter

The outcome exhibit existence of lots of ripple in the waveform showing an extremely high THD. It denotes that THD is more than 60% which needs to be minimized to around 5%. To accomplish the expected objective an average current controller employing boost converter is created.

C. *Average Current Control Method using Boost Converter*

The circuit diagram of Average Current Control technique employing Boost Converter is presented below in Figure.8. PSIM computer software is employed for the design of the circuit. The input voltage for the bridge rectifier is 220$V_{RMS,}$ and output voltage of the boost converter is 600V for a Duty cycle of 0.6. On the other hand values of PI controller are selected according to the circuit prerequisites

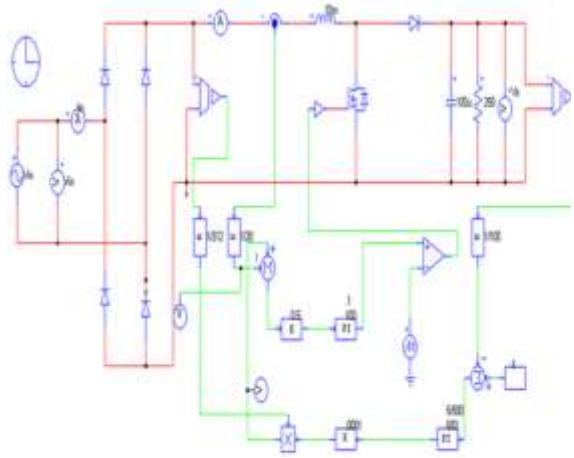

Fig .8 Simulation diagram of Average Current Control Method Applied to Boost converter for Fixed load

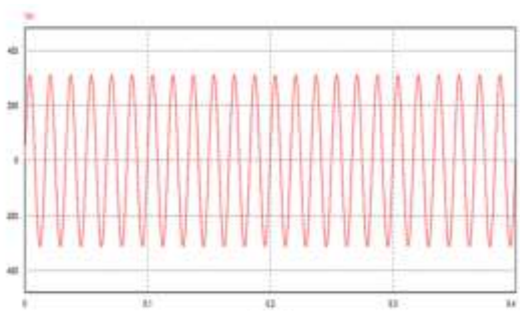

Fig.9 Input voltage waveform of Average Current Control Method Applied to Boost converter for Fixed load

The simulation outcomes are presented below. The input voltage for the bridge rectifier is presented in Figure.9, which is 220V_{RMS}.Due to boost converter circuit output, is greater than the input. The output voltage is 600V DC for a duty cycle of 0.6. The output waveform is presented in Figure.10

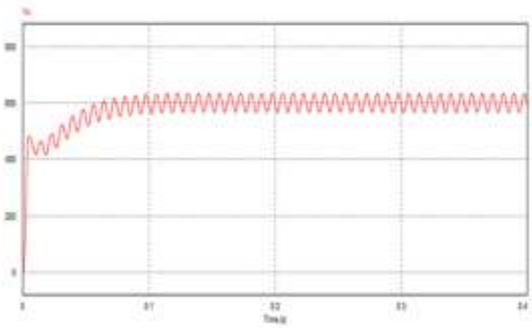

Fig.10 Output Voltage waveform of Average Current Control Method Applied to Boost converter for Fixed load

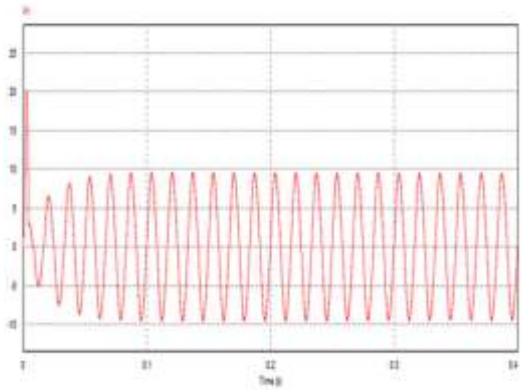

Fig.11 Input Current waveform of Average Current Control Method Applied to Boost converter for Fixed load

The waveform reveals the existence of no ripples, hinting towards a good THD value. The THD and PF values are found to be 3.06% and 0.985 respectively.

D. Average Current Control Method Applied to Boost Converter For Variable Load

The circuit diagram is presented in Figure.12, which exhibits the Average Current Control Method for variable load. The step size of 0.2 sec is chosen whereas the parallel resistance of 500 ohms is selected. It is obvious from Figure.14 that after 0.2 sec step output voltage, input current and input voltage falls to 0.2, after it recovers to the original position.

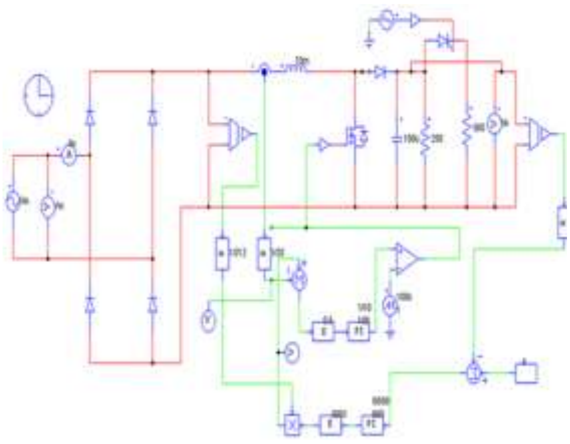

Fig.12 Simulation circuit of Average Current Control Method Applied to Boost converter for Variable Load

The output voltage waveform for a duty cycle of 0.6 is presented in Figure.13.

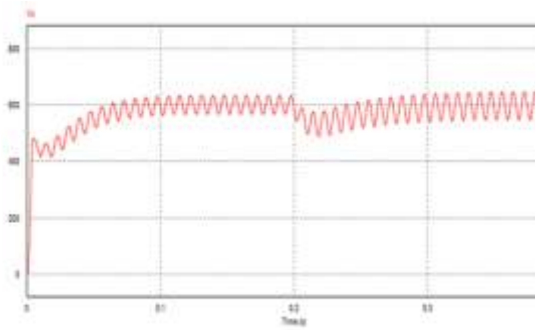

Fig.13 Output Voltage waveform of Average Current Control Method Applied to Boost converter

The input current waveform for a duty cycle of 0.6 is presented below in Figure.14 displays the change at 0.2 sec.

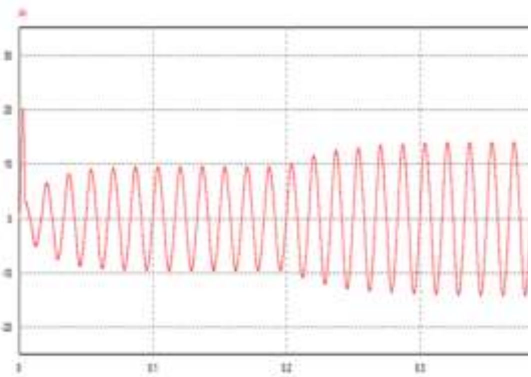

Fig.14 Input Current waveform of Average Current Control Method Applied to Boost converter for Variable load

After employing the variable load, the THD and PF values are found to be 3.23% and 0.97 respectively.

CONCLUSION

THD reduction and PF correction of Boost Converter employing Average current control method is presented in this paper. PSIM software has been used for circuit design, measurement of THD and PF. Initially, results (THD and PF) of open loop uncontrolled rectifier is presented, accompanied by detailed description of the average current control technique. The average current control method contributed towards enhancement of the performance and improvement of the results (THD and PF). In the results of uncontrolled rectifier, it is observed that harmonics are extremely large. Closed loop controlled rectification is then employed for harmonics reduction and PI controllers are tuned to obtain the satisfactory results. In addition the transient and steady state analysis of average current control method is also provided, which indicates positive results. Eventually an improved THD value of 4% is attained using simulation.

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