



Single Phase Interleaved Boost Converter using Average Current Control Technique for PF & THD Improvement

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Abstract:

This paper presents the Power Factor Control and Reduction in Total Harmonics Distortion by using Boost and Interleaved Boost Converter using Average Current Control Technique involving Proportional and Integral (PI) Controllers. By using this Technique, supply current Power Factor can be improved to near unity and Total Harmonics Distortion in Supply Current can be reduce. In this Technique the input voltage and inductor current of Boost and IB Converter are sensed by an Average PI Controller for the closed loop, and Pulse Width Modulation can be achieved by comparing the Average PI Controller output with the Sawtooth waveform, which is then fed to the switching device. The Off time of the switching device are determined by the time at which the average inductor current reaches to the reference current limit. This involves an inner fast current control loop. The paper presents the control technique and performance analysis including Power Factor as well as THD of Boost and IB Converters.

Keywords: AC-DC Power Converter, Average Current Control, Boost Converter, Interleaved Boost Converter, Power Factor Correction, Total Harmonics Distortion.

I. INTRODUCTION

With the advent of Power Electronic Devices, the loads connected to the mains are becoming nonlinear. These nonlinear loads are majorly responsible for the distortion of input sinusoidal waveform. The distortion in the input Sinusoidal waveform can be analyzed as the summation of higher frequency sinusoidal components which are termed as harmonics [2]. The Distorted input waveform also results in the poor input Power Factor. As per Government regulations, the input harmonics currents is to be restricted, also the supply power factor to be maintained near to unity. As a result there is a need of Power Factor correction and reduction of Total Harmonics Distortions Circuit [3]. Power factor can be improved to some extent by use of passive filters i.e. by connecting inductors at input stage. For higher value of inductor at input side, the inductor stores enough energy to keep the rectifier ON for half cycle. Hence harmonics content due to discontinuous conduction of rectifier is reduced. But use of passive filters requires big and bulky inductors, as they are connected directly to AC Mains and is operated at frequency of AC mains. An active filter implied effectively can improve power factor and reduce Harmonics, but the problem of power factors and harmonics cannot be solved completely [10]. Our prime concern is to improve input power factor by reducing input harmonics current as per IEEE Standards IEEE 519, IEC 1000-C, IEC 6000-3-2 margins. Hence in order to achieve such standards, there is a need of Active Power factor correction and Harmonics reduction techniques [1]. Active power control techniques offers improved Power factor with reduced Harmonics and are significant ally smaller and lighter than Passive filters. It regulates the switching device to drive the input current from power line in proportional to input voltage of the converter. It has input current loop feedback to control the input current and regulate output voltage of the converter [3].

The most known method of power factor improvement and harmonics reduction is by use of PFC boost converter. But in PFC Boost converters there are ripples in input current which can be minimized by use of Interleaved Boost converter with Proportional and Integral (PI) Average current control technique. The interleaved boost converter, both the Boost Converter operates in 180° out of phase. The input current comprises of the sum of two inductor currents. These two out of phase inductor input currents cancel each other ripples and reduces ripples in the input current of the Interleaved Boost Converter [13]. The main focus of this paper is to design and implication of Interleaved Boost converter with Proportional and Integral (PI) Average current control technique.

II. BOOST CONVERTER

A Boost Converter is a DC-DC Power converter which is used to step up the input voltage to output voltage. In boost converter, the output voltage is higher than input voltage. When switch is ON, the current flows through the inductor and stores energy. When switch is OFF, the stored energy of the inductor will be in additive polarity and adds up with input voltage in series and cumulative charge the output capacitor which gives the step up output voltage [14]. The basic working principle of boost converter consists of two distinct states:

1. Durring On state, switch S is closed which results in increase of inductor current.
2. Durring Off state, switch S is open the only path to the flow of current is through inductor L1, Diode D, capacitor C1, and load R. this results in transferring accumulated energy to the capacitor.

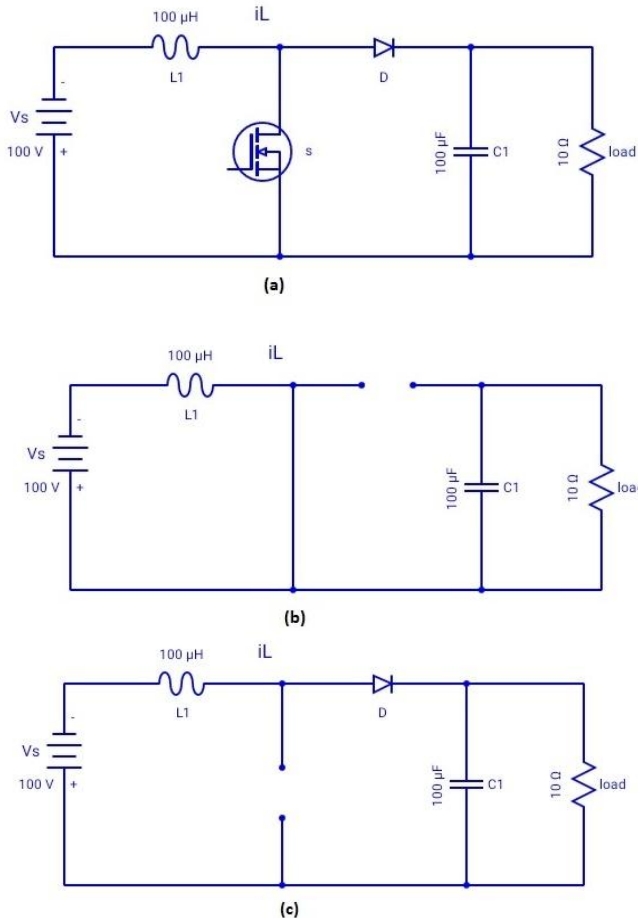


Figure.1. Circuit configuration of a boost converter: a)With operational switch b) ON-state, c) OFF-state.

Continues Conduction Mode:

Boost converter operating in Continues Conduction Mode, the Inductor current i_{L1} never falls to zero. Figure 2 shows the typical waveform of Inductor current and output voltage of the boost converter operating in continues conduction mode.

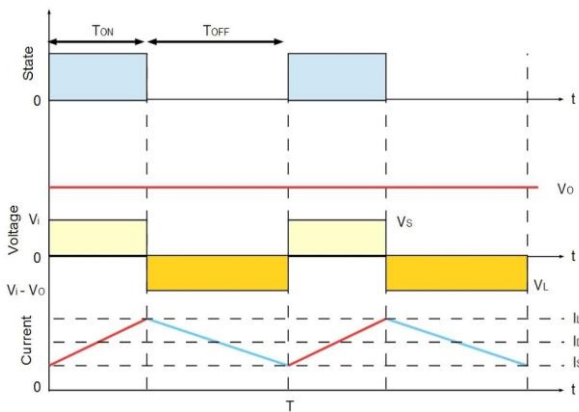


Figure.2. Waveforms of current and voltage in a boost converter operating in continuous mode.

Discontinues Conduction Mode:

Boost converter operating in Discontinuous Conduction Mode, due to high ripple current the inductor current i_{L1} does not flow continuously. There is a time interval where during switch Off interval where current is zero till next turn On of switch S. Figure 3 shows the typical waveform of Inductor current and output voltage of the boost converter operating in discontinues conduction mode.

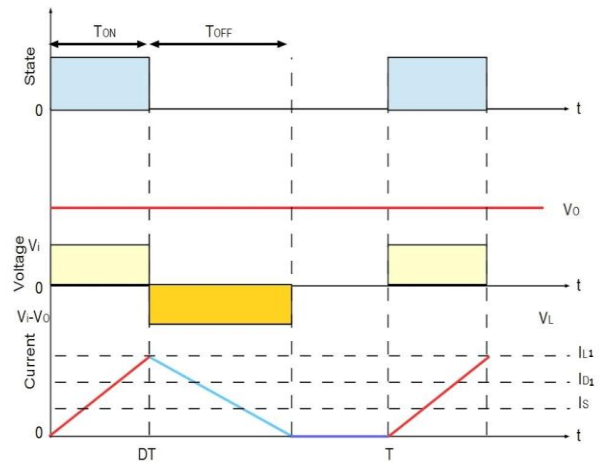


Figure.3. Waveforms of current and voltage in a boost converter operating in discontinuous mode.

III. INTERLEAVED BOOST CONVERTER

Interleaved boost converters are mainly used in power conversion applications involving high input to high output voltage conversion. In interleaved boost converter conduction losses can be reduced by splitting the inductor current two parallel power path hence increasing the overall efficiency as compared to the boost converter [12]. The operational circuit of Interleaved Boost Converter is shown in figure 4. Here VS is the source voltage, VL1 and VL2 are the voltage across the parallel inductors 1 and inductor 2 respectively. Also current flowing across the inductors 1 and 2 are i_{L1} and i_{L2} respectively. i_c and i_o are the current across the output capacitor and Load resistance.

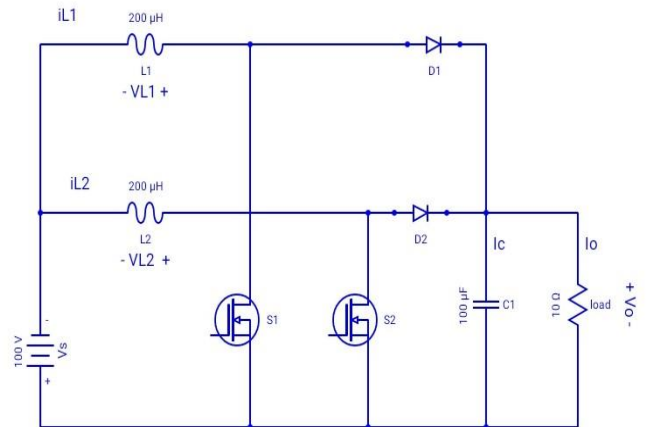


Figure.4. Circuit configuration of an interleaved boost converter with operational switch

The working of Interleaved boost converter is divided into four modes, they are:-

1. Switches S1 and S2 are ON, and Diode D1 and D2 are OFF as shown in figure 5. The current ramps up in L1 and L2 respectively, depending upon the input voltage. Hence energy is stored in L1 and L2 respectively.

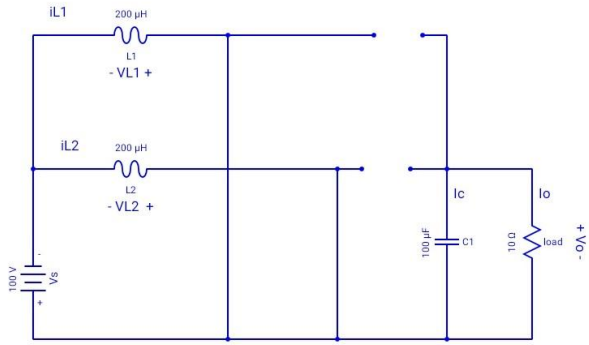


Figure.5. Circuit configuration of a interleave boost converter with operational switch S1 and S2 On.

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1}$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2}$$

$$\frac{dV_o}{dt} = \frac{-V_o}{RC}$$

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_o}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -1/RC \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_o \end{bmatrix} + \begin{bmatrix} 1/L_1 \\ 1/L_2 \\ 0 \end{bmatrix} V_s$$

- Switch S1, diode D2 are On and Switch S2, Diode D1 are Off as shown in figure 6. Hence the stored energy adds up to the input voltage to give high output voltage also current IL2 ramps down depending upon difference in input and output voltage.

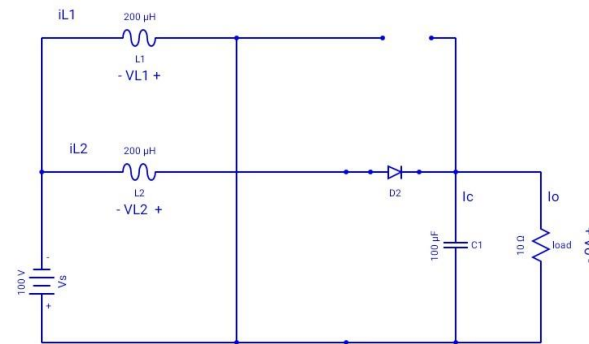


Figure.6. Circuit configuration of a interleave boost converter with operational switch S1 On and S2 Off

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1}$$

$$\frac{di_{L2}}{dt} = \frac{L_2}{L_1} \frac{V_o}{V_s} - \frac{V_o}{L_1}$$

$$\frac{dV_o}{dt} = \frac{i_{L2}}{C} - \frac{V_o}{RC}$$

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_o}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & -1/L_1 \\ 0 & 1/L_2 & -1/RC \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_o \end{bmatrix} + \begin{bmatrix} 1/L_1 \\ 1/L_2 \\ 0 \end{bmatrix} V_s$$

- Switch S2 and Diode D1 are On, Switch S1 and Diode D2 are Off as shown in figure 7. This mode is

same as mode 2 but in this mode the stored energy adds up to the input voltage to give high output voltage also current IL1 ramps down depending upon difference in input and output voltage.

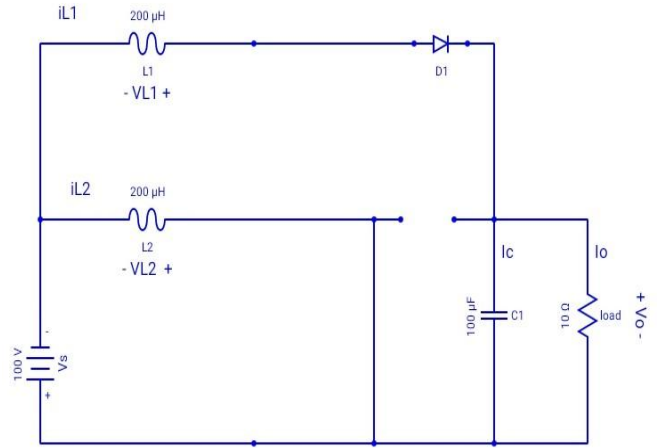


Figure.7. Circuit configuration of a interleave boost converter with operational switch S1 Off and S2 On.

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} - \frac{V_o}{L_1}$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} - \frac{V_o}{L_2}$$

$$\frac{dV_o}{dt} = \frac{i_{L1}}{C} - \frac{V_o}{RC}$$

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_o}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & -1/L_1 \\ 0 & 0 & 0 \\ 1/C & 0 & -1/RC \end{bmatrix} \begin{bmatrix} I_{L1} \\ I_{L2} \\ V_o \end{bmatrix} + \begin{bmatrix} 1/L_1 \\ 1/L_2 \\ 0 \end{bmatrix} V_s$$

- Switch S1 and S2 are Off, Diode D1 and D2 are On as shown in figure 8. The stored energy of L1 and L2 is delivered to the the output capacitor and load. As a result of which both IL1 and IL2 ramps down depending upon the difference in input and output voltage.

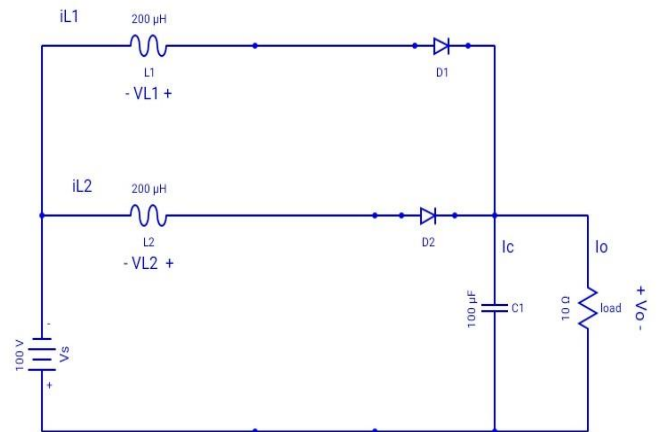


Figure.8. Circuit configuration of a interleave boost converter with operational switch S1 and S2 Off.

$$\frac{di_{L1}}{dt} = \frac{V_s}{L_1} - \frac{V_o}{L_1}$$

$$\frac{di_{L2}}{dt} = \frac{V_s}{L_2} - \frac{V_o}{L_2}$$

$$\frac{dV_o}{dt} = \frac{i_{L1}}{C} - \frac{V_o}{RC}$$

$$\begin{bmatrix} \frac{di_{L1}}{dt} \\ \frac{di_{L2}}{dt} \\ \frac{dV_o}{dt} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \frac{-1}{L_1} \\ 0 & 0 & \frac{-1}{L_2} \\ \frac{1}{C} & 0 & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_{L1} \\ i_{L2} \\ V_o \end{bmatrix} + \begin{bmatrix} \frac{1}{L_1} \\ \frac{1}{L_2} \\ 0 \end{bmatrix} V_s$$

IV. AVERAGE CURRENT MODE CONTROL

Average Current Mode control Technique is a good method to control input current. In this method the current flowing through the inductors are sensed and is filtered by using current error amplifier whose output is used to drive Pulse Width Modulation. As a result of which the inner current loop minimizes the error. Hence input current wave form exactly follows the input voltage wave form so the power factor is improved and harmonics are reduced [15]. An Average Current Mode Control is shown in figure 9.

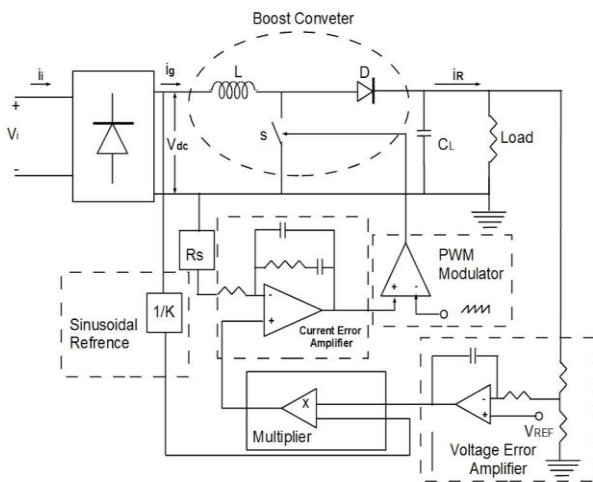


Figure. 9. Schematic of Average Current mode control

Average Current Control Mode has various advantages which are as follows:

1. Its switching frequency is constant.
2. It does not require any compensation ramp.
3. Its control is less sensitive to communication noise.
4. It gives a very smooth input current waveform.

V. SIMULATIONS AND RESULTS

The paper involves simulation of Boost and Interleaved Boost converter circuits with gradual increase in the Power Factor control and consecutive reduction in Harmonics. All Simulation is performed in MATLAB Simulink. First method of power factor correction for non linear loads is referred to as Passive Power factor correction as shown in figure 10. Its input current waveform and THD Calculation using FFT analysis is shown in figure 11.

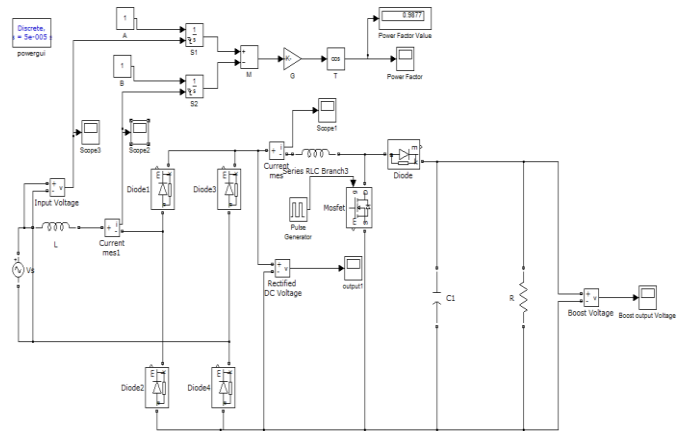
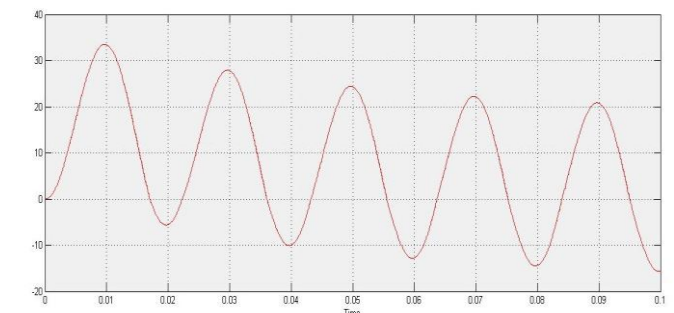
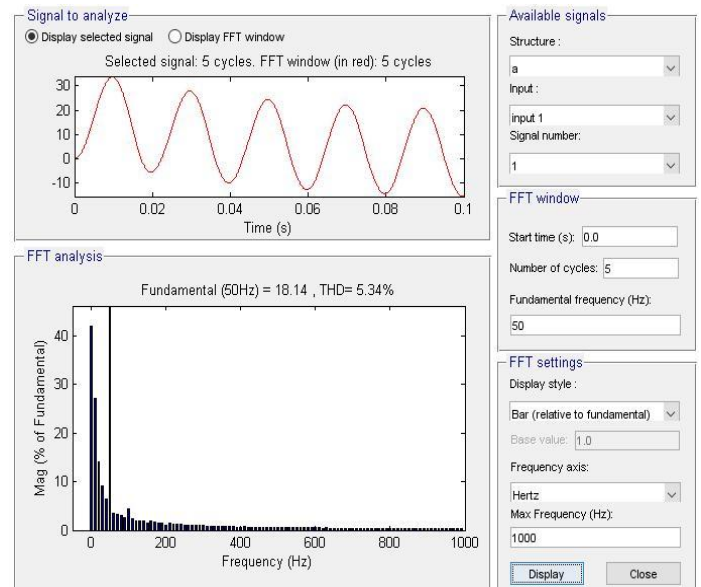


Figure.10. Simulink Model of PFC Boost Converter using Passive Input Filter.



(a)



(b)

Figure.11. (a) Input Current Waveform, (b) FFT Analysis of Input Current waveform of Boost Converter

It is clear from the figure that Total Harmonics Distortion is high ie 5.34%. Here Corresponding Power Factor found to be 0.9877 Lagging. Second method of power factor correction for non linear loads is referred to as Active Power factor correction. In active power factor control, average current control technique using PI Controller for power factor correction is used as shown in figure 12. Also its input current waveform and THD Calculation using FFT analysis is shown in figure 13.

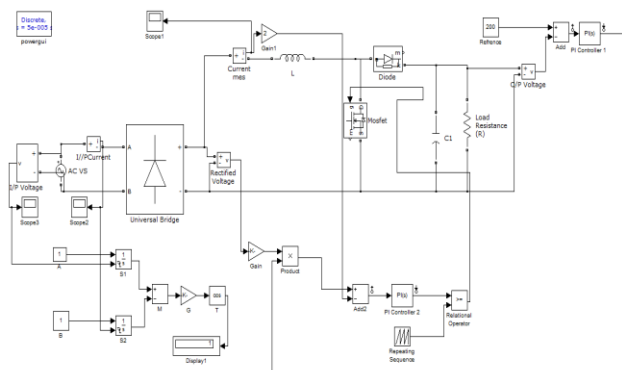
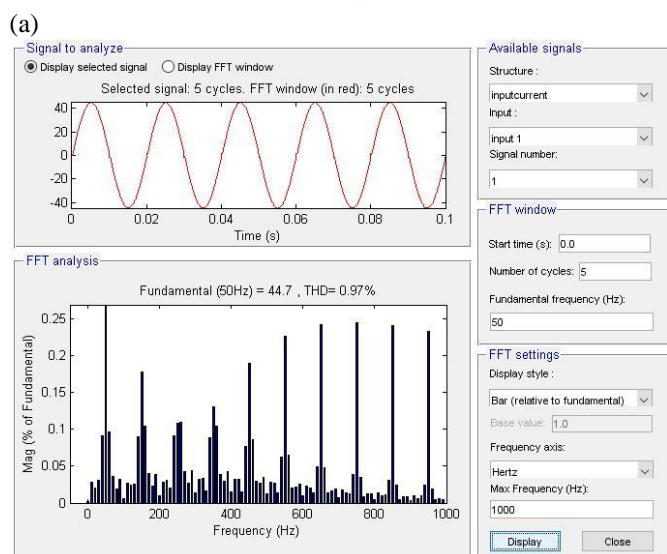
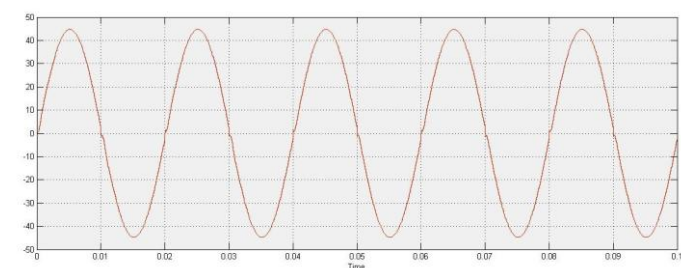


Figure.12. Simulink Model of PFC Boost Converter using Active PFC Control.



(b) Figure.13. (a) Input Current Waveform, (b) FFT Analysis of Input Current waveform of PFC Boost Converter.

It is clear from the figure that Total Harmonics Distortion is reduced to 0.97%. Also Corresponding Power is improved to 0.9977 Lagging. Though power factor is improved by using boost converter, but there is fair amount of ripple present in the input current. So interleaved boost converter with average current mode control using PI controller is proposed as shown in figure 14. Also its input current waveform and THD Calculation using FFT analysis is shown in figure 15.

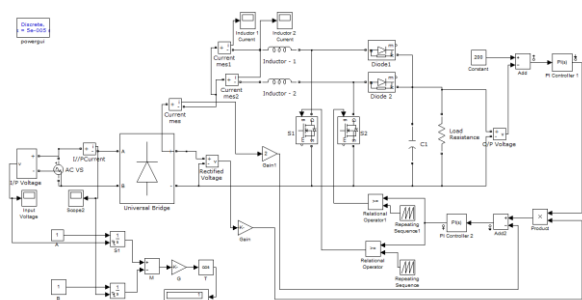
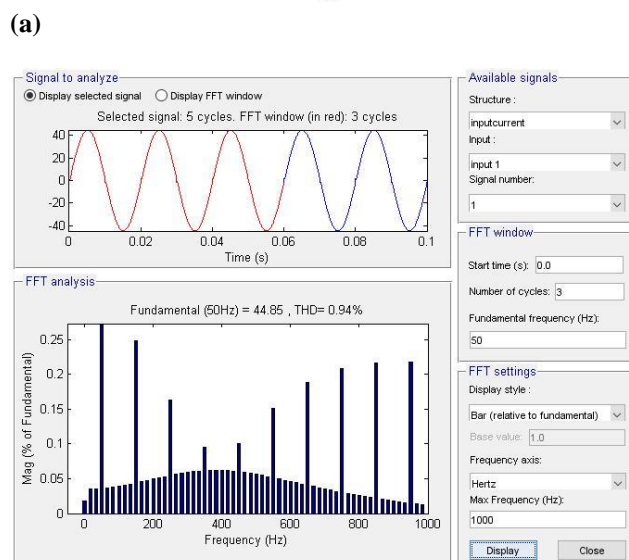
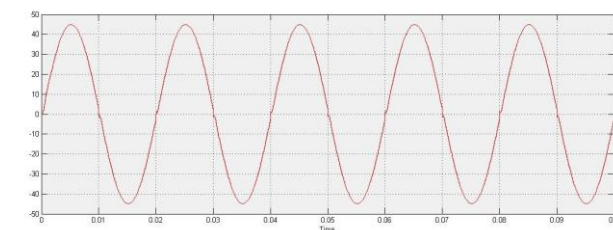


Figure.14. Simulink Model of PFC Interleaved Boost Converter using Active PFC Control



(b) Figure.15. (a) Input Current Waveform, (b) FFT Analysis of Input Current waveform of PFC Interleaved Boost Converter.

It is clear from the figure that Total Harmonics Distortion is reduced to 0.94%. Also Corresponding Power is improved to 0.9998 Lagging. Also ripple content of input current waveform is reduced.

TABLE.I. COMPARATIVE ANALYSIS OF PF & THD

S.No.	Converter Type	PF	THD (%)
1	Boost Converter	0.987	5.34
2	PFC Boost Converter	0.997	0.97
3	PFC Interleaved Boost Converter	0.998	0.94

The average PI current controlled closed loop for boost converter is described, analyzed and compared. The fundamental issues Power factor correction, Output voltage regulation, Total Harmonic Distortion, Output voltage ripple and inductor current ripple is discussed.

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