Power Factor Correction by Interleaved Boost Converter Using PI Controller

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***Abstract*—In the electricity distribution network, all the connected equipments usually require rectification. For rectification, conventional single phase diode rectifiers are used with a large electrolytic capacitor to reduce ripple in output DC voltage, but it produces a non-sinusoidal line current. Therefore, various techniques for power factor correction (PFC) are getting remarkable attention. Among all other topologies of PFC, the popularly used topology is boost topology. This paper gives a detailed explanation about a two-phase interleaved boost converter which ensures 180˚ phase shift between the two interleaved converters. To reduce the harmonics by reshaping the input current a PI controller is used.**

Keywords*— *Average Current mode control, Boost converter, Interleaved Boost converter, PI controller, Power factor

I. INTRODUCTION

The improvement in the Power factor is an important feature to be considered in the field of power electronics research. For doing this, there are many considerable methods have been developed. One of them is to use active single phase rectifiers operating with unity power factor. Single phase diode rectifiers are the mostly used circuits for those applications where the ac supply is used as input (e.g.:- computers, telecommunications, air conditioning etc). In these types of classical converters the input ac supply voltage is converted into dc and output is taken passing it through a large filter capacitor. [1]. The filter capacitor minimizes the ripple present in the output voltage but introduces distortion in the input current due to which the power factor is reduced. Hence to improve the Power Factor many PFC techniques are used. Passive PFC techniques have limitations in the amount of correction achieved. Much better result can be achieved by active PFC technique [2],[3]. The popularly used technique for active PFC is boost converter. It draws continuous input current but this current can be manipulated by average current mode control technique. But there are ripple in the input current due to inductor used in boost converter which can be minimized with the help of two phase interleaved boost converter. In two phase interleaved boost converters, both the boost converters are operated in 180˚ out of phase. The input current comprises with two inductor currents i.e. the sum of two inductor currents. As the inductor's ripple currents are out of phase so they cancel out each other and reduce the ripples in input current caused by the boost converter. This paper presents average current mode control of interleaved boost converter using PI controller which provides higher power factor with better control [4],[5],[6]. In this paper simulation of single phase diode rectifier, simulation of Boost converter with PI controller and then simulation of interleaved boost converter with PI controller is given to show that average current mode controlled interleaved boost converter with PI controller provides best power factor. All the simulation work is done in MATLAB- Simulink.

II. NEED FOR POWER FACTOR IMPROVEMENT

Power factor (pf) is defined as the ratio of the real power (P) to apparent power (S) or the cosine (for pure sine wave for both current and voltage) that represents the phase angle between the current and voltage waveforms. The power factor can vary between 0 and 1, and can be either inductive (lagging, pointing up) or capacitive (leading, pointing down). In order to reduce an inductive lag, capacitors are added until pf equals 1. When the current and voltage waveforms are in phase, the power factor is 1 (cos (0°) = 1). The whole purpose of making the power factor equal to one is to make the circuit look purely resistive (apparent power equal to real power).

Power factor is defined as the cosine of the angle between voltage and current in an ac circuit. If the circuit is inductive, the current lags behind the voltage and power factor is referred to as lagging. However, in a capacitive circuit, current leads the voltage and the power factor is said to be leading.

Power factor can also be defined as the ratio of active power to the apparent power. The apparent power is given by the product of R.M.S. values of applied voltage and circuit current. The active power is the power which is actually dissipated in the circuit resistance.

The reactive power is developed in the inductive reactance of the circuit.

Power factor = (Active power)/ (Apparent power)

A load with a low power factor draws more current than a load with a high power factor for the same amount of useful power transferred. The higher currents increase the energy lost. So power factor improvement is required.

III. Single Phase Diode Rectifier

Single phase diode rectifiers are commonly used to convert ac into dc. But in the rectified dc voltage considerable amount of ripple is present. So to reduce this ripple a filter capacitor is used. A single phase diode rectifier with a filter capacitor is shown in Fig.1.

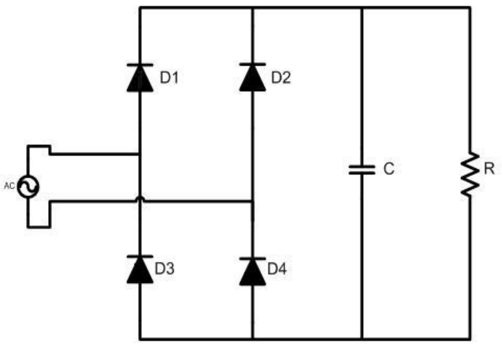

Fig. 1. Single phase diode rectifier with filter capacitor.

Although a filter capacitor minimize the ripple from the output voltage, but it introduces distortion in the input current which causes discontinuous current drawn from the supply voltage. The capacitor draws pulsating current only when the input ac voltage is greater than the capacitor voltage, which occurs at the line voltage peaks. So due to the use of filter capacitor the power factor becomes poor and introduces several problems including reduction of available power and increased loss. The waveform of the rectified voltage and distorted input current is shown in Fig.2.

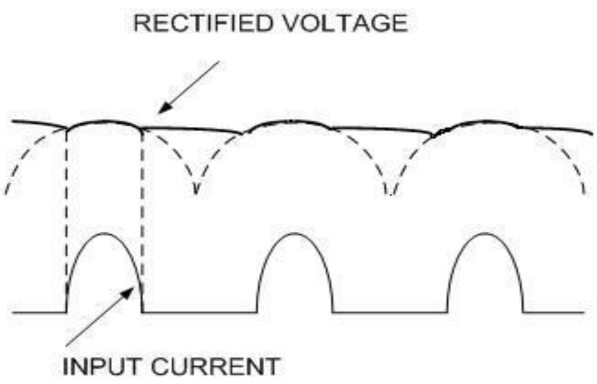

Fig. 2. Pulsating input current waveform.

IV. Boost Converter

To eliminate the problem of discontinuous input current various PFC techniques are used. But active PFC techniques based on switch mode power converters may give the best result. The boost topology is widely used than other PFC techniques. The circuit configuration of the proposed AC to DC convertor is shown in fig. 2. Basically, the proposed convertor consist of a front end diode D5 rectifier in series with a boost type inductor L1 and active switch to control the output DC voltage. The circuit diagram of a boost converter is shown in Fig.3.

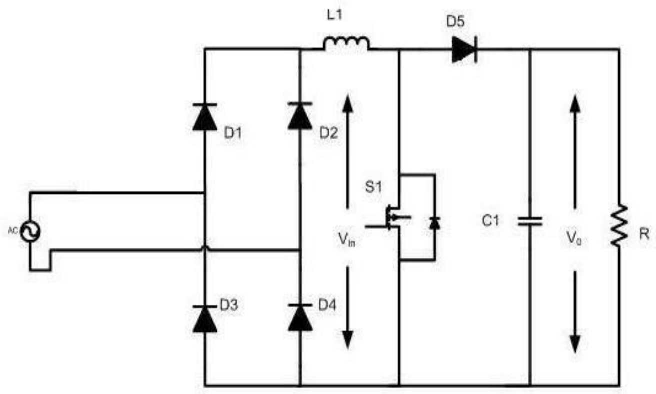

Fig. 3. Boost converter.

When the switch S1 is ON, the current I_L increases and flows through inductor L. When switch S is OFF the current I_L decreases and flows through L, diode D5, C, and R. The current I_L falls until switch S is turned on again.

So when switch S is on:

$$\frac{dI}{Ldt} = \frac{V_i}{L} \tag{1}$$

Again when switch is off:

$$\frac{dI}{Ldt} = \frac{V_0 - V_i}{L} \tag{2}$$

Here V_{in} is the rectified input voltage and V_0 is the output voltage. So the boost converter draws continuous input current. This input current can be controlled to follow a sinusoidal reference using average current mode control technique.

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V. Design Of The Converter

The block diagram of close loop converter is shown in fig.4. The error voltage between the output voltage and the reference voltage is fed to the PI controller. A proportional-integral controller (PI controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PI controller calculates an error value as the difference between a measured process variable and a desired set point. The PID controller algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: proportional, integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element. The PI controller used in our simulation attempts to minimize the error by adjusting the process through use of a manipulated variable. Practically a fixed frequency triangular modulating waveform is used for getting the controlling signal for Switch S.

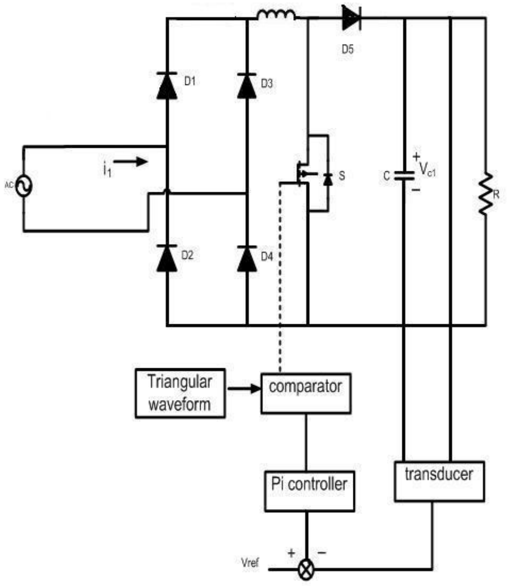

Fig. 4. Circuit diagram of proposed converter.

At last the component rating of convertor is explained. The diode D5 and switch S have the same peak current rating. Also the peak reverse blocking voltages of switch S1 and diode D5 have respective maximum output voltage. Because the converter operates in discontinuous mode, the switching losses appear only when switch S1 is made off. Therefore, a RC snubber can be applied to save switch S and mitigate switching losses.

VI. Interleaved Boost Converter

While using boost converter ripple is present in the input current because of rise and fall of the inductor current. This problem can be eliminated by using interleaved boost converter. The interleaved boost converter is shown in Fig.5.

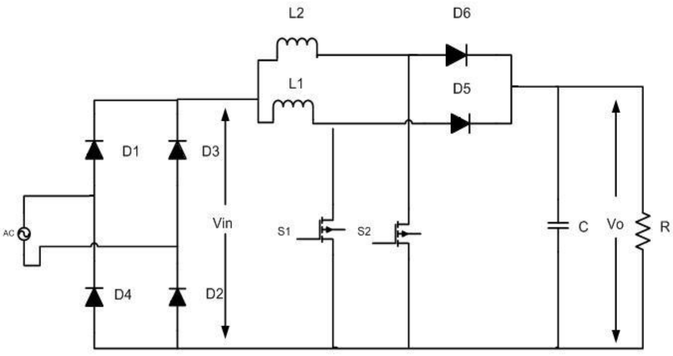

Fig. 5. Interleaved boost converter.

In interleaved boost converter, there are two boost converters are used which operate in 180˚ out of phase. The input current is the sum of two inductor currents IL1 and IL2. Here ripple currents from two inductors are out of phase so they cancel each other out and reduce the input ripple current that the boost converter cause.

When switch S1 is on and switch S2 is off:

$$\frac{dI_{L1}}{dt} = \frac{V_i}{L1} \tag{3}$$

$$\frac{dI_{L2}}{dt} = \frac{V_0 - V_i}{L2} \tag{4}$$

When switch S1 is off and switch S2 is on:

$$\frac{dI_{L1}}{dt} = \frac{V_0 - V_i}{L1} \tag{5}$$

$$\frac{dI_{L2}}{dt} = \frac{V_i}{L2} \tag{6}$$

The two inductor currents will be out of phase and cancel out the ripple of each other if:

$$\frac{V_i}{L1} = \frac{V_0 - V_i}{L2} \tag{7}$$

$$\frac{V_0 - V_i}{L1} = \frac{V_i}{L2} \tag{8}$$

The above two equations i.e. equation (7) and equation (8) will be satisfied if and only if L1 = L2 and $V_0 = 2V_0$.

In this paper power factor correction by the interleaved boost converter using average current mode control with PI controller is shown by simulation.

VII. Simulation And Results

First of all the simulation of single phase diode rectifier is done. The MATLAB-Simulink model of single phase diode rectifier with filter capacitor is shown in Fig.6.

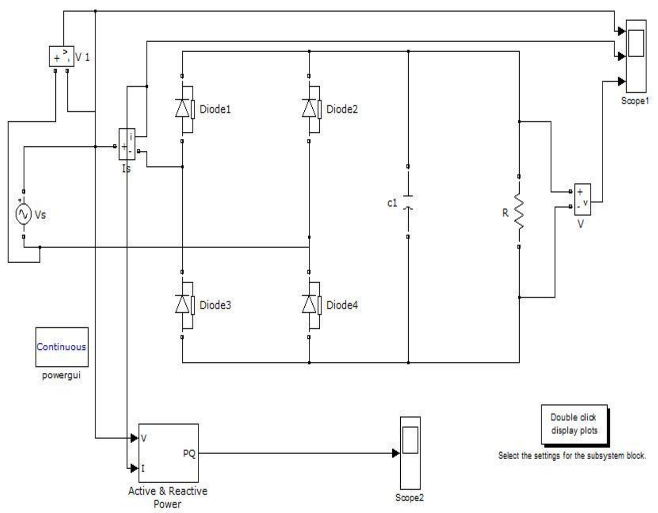

Fig. 6. Simulation diagram of single phase diode rectifier.

The waveforms are shown in Fig.7 and Fig.8.

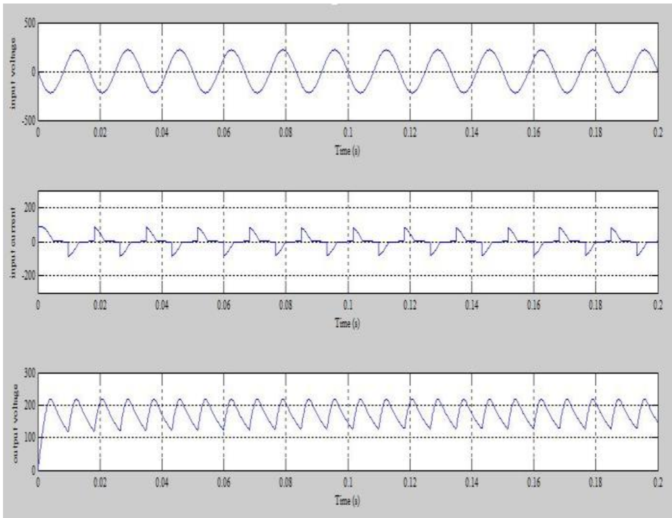

Fig. 7. Input ac voltage, Input ac current and Output voltage waveforms.

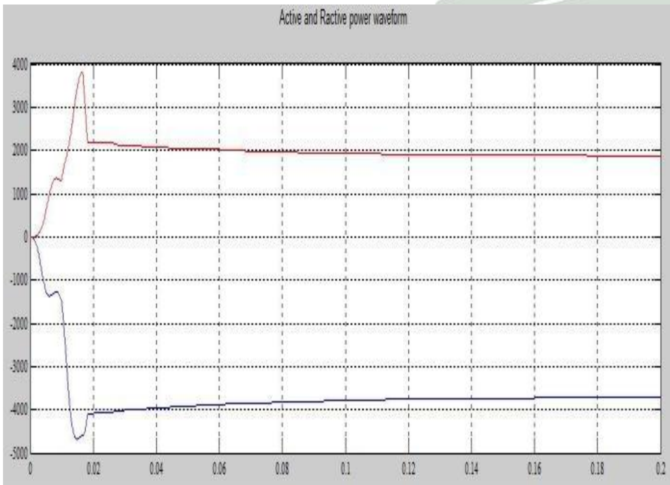

Fig. 8. Active and reactive power waveform.

From Fig.7 we can see that the input current is discontinuous and pulsating. As a result the power factor is poor. The power factor can be calculated by active and reactive power shown in Fig.8. In this case the input power factor is 0.8656.

To improve the power factor boost converter is used. The MATLAB-Simulink model using boost converter is shown in Fig.9.

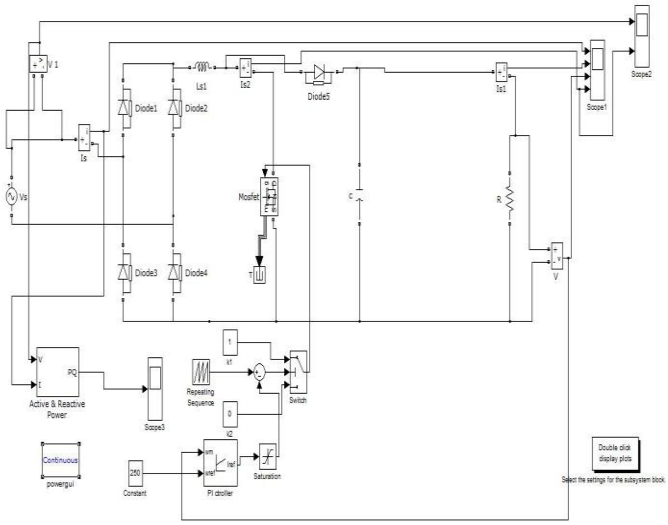

Fig. 9. Simulation diagram using boost converter.

The corresponding waveforms are shown in Fig.10 and Fig.11.

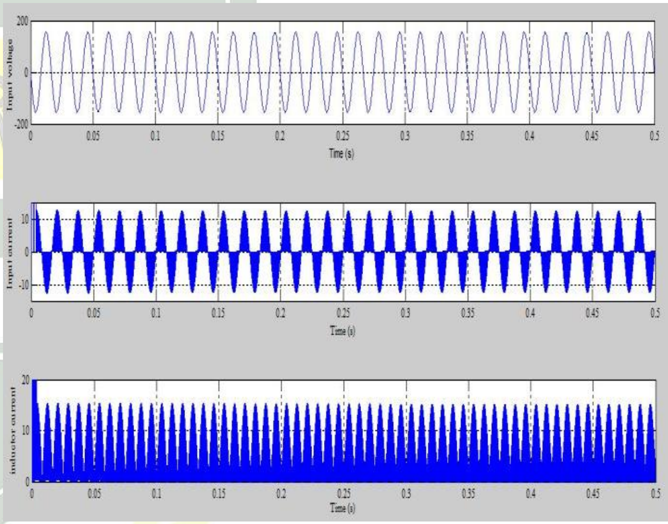

Fig. 10. Input ac voltage, input ac current, inductor current waveforms.

As we can see that due to the use of boost converter with average current mode control by PI controller the input current is of sinusoidal shape. Hence the power factor improved very much.

In this case the input power factor is 0.9876. Though the 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. The MATLAB-Simulink model using interleaved boost converter is shown in Fig.11.

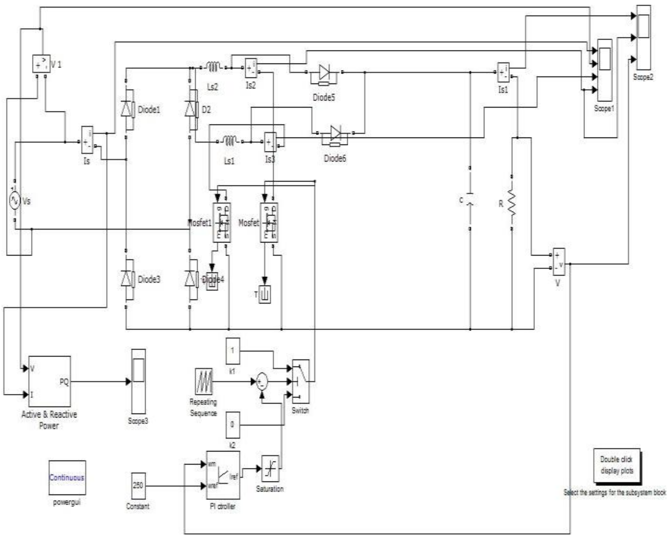

Fig. 11. Simulation diagram using interleaved boost converter.

Here the input ac voltage is taken 155v (R.M.S.) and the reference output voltage is taken 270v to minimize the ripple of the input current. The corresponding waveforms are shown in Fig.12.

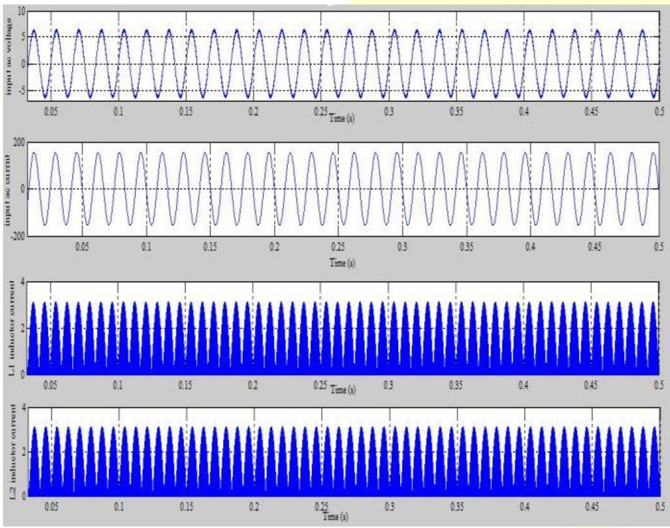

Fig. 12. Input ac voltage, input ac current, L1 inductor current, L2 inductor current.

We can see in Fig.14 that the input current perfectly sinusoidal. As a result the input power factor is improved very much.

CONCLUSION

The power factor correction circuits are simulated by MATLAB Simulink. It is seen that best power factor is obtained in case of interleaved boost converter with average current mode control using PI controller.

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