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Power Factor Correction By Interleaved Boost Converter Using PI Controller

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ABSTRACT
The equipment connected to an electricity distribution network usually needs rectification. The conventional single phase diode rectifier uses a large electrolytic capacitor to reduce DC voltage ripple, which produces a non-sinusoidal line current. So power factor correction (PFC) techniques are gaining increasing attention. The boost topology is most popular than others in PFC applications. This paper presents a two-phase interleaved boost converter which ensures 180˚ phase shift between the two interleaved converters. The PI controller is used to reshape the input current so as to reduce the harmonics.
Keywords – Average Current mode control, Boost converter, Interleaved Boost converter, PI controller, Power factor.

I. INTRODUCTION

Single phase diode rectifiers are the most commonly used circuits for application where the input is the ac supply (e.g.:- computers, telecommunications, air conditioning etc). These classical converters operate by rectifying the input ac line voltage and filtering it with large capacitor. The filter capacitor reduces the ripple present in the output voltage but introduces distortion in the input current which reduces the power factor. So PFC techniques are used. Improvements that can be achieved by passive PFC techniques are limited. Much better result can be achieved by active PFC technique [1]. The most popular topology for active PFC is boost converter as it draws continuous input current. This input current can be manipulated by average current mode control technique [2], [3]. But there are ripple in the input current due to inductor of boost converter which can be minimized by using two phase interleaved boost converter [4], [5], [6]. In two phase interleaved boost converter two boost converters operate in 180˚ out of phase. The input current is the sum of two inductor currents. As the inductor's ripple currents are out of phase they cancel each other out and reduce input ripple current that the boost converter cause. This paper introduces average current mode control of interleaved boost converter using PI controller which provides higher power factor and also provides better control. 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 carried out in MATLAB- Simulink.

II. NECESSITY OF POWER FACTOR IMPROVEMENT

Power factor is a figure of merit that measures how effectively power is transmitted between a source and load network. It always has a value between zero and one. The unity power factor condition occurs when the voltage and current waveforms have the same shape, and are in phase.

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.

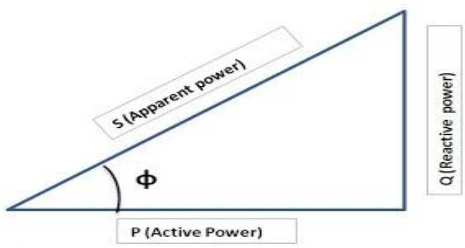

Fig.1. Power triangle

The power triangle is shown in Fig.1. 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 for ac-dc conversion. But the rectified dc voltage contains fair amount of ripple. To reduce this ripple a filter capacitor is used. A single phase diode rectifier with a filter capacitor is shown in Fig.2.

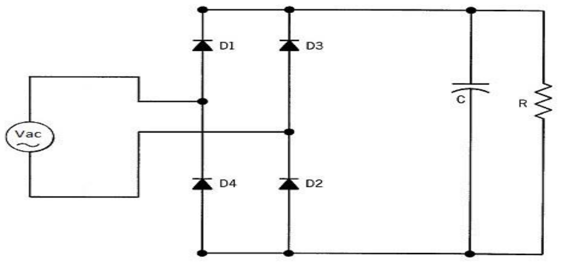

Fig.2. Single phase diode rectifier with filter capacitor

Although a filter capacitor suppresses the ripple from the output voltage, it introduces distortion in the input current and draws current from the supply discontinuously, in short pulses. 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.3.

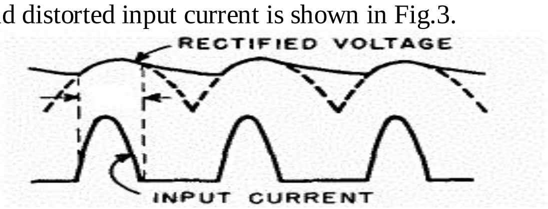

Fig.3. Pulsating input current waveform

IV. BOOST CONVERTER

To prevent the problem of pulsating input current PFC techniques are used. Best result can be obtained by using active PFC techniques based on switch mode power converters. The boost topology is by far more popular than other PFC techniques. The circuit diagram of a boost converter is shown in Fig.4.

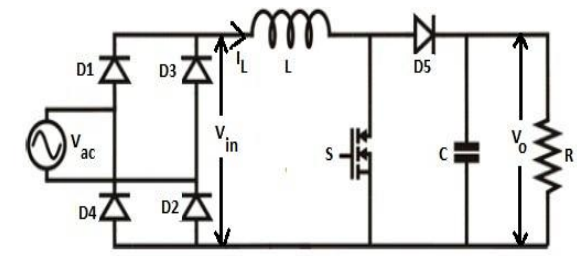

Fig.4. Boost converter

When the switch S is on the current I_L rises 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:

$$\frac{dI_L}{dt} = \frac{V_{in}}{L} \quad (1)$$

Again when switch is off:

$$\frac{dI_L}{dt} = \frac{V_o - V_{in}}{L} \quad (2)$$

Here V_{in} is the rectified input voltage and V_o 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.

V. AVERAGE CURRENT MODE CONTROL

Average current mode control allows a good input current waveform. Average current mode control is represented in Fig.5.

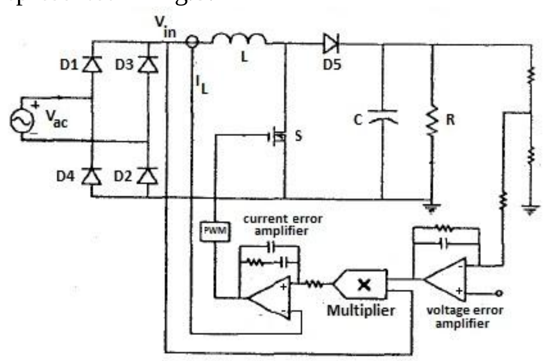

Fig.5. Average current mode control

Here inductor current is sensed and filtered by a current error amplifier whose output drives a PWM modulator. In this way the inner current loop minimize the error. As a result the input current is made to follow the waveform of the input voltage.

Average current mode control has several advantages like, constant switching frequency, not requirement of compensation ramp, control is less sensitive to commutation noise, good input current waveform etc.

VI. INTERLEAVED BOOST CONVERTER

In case of boost converter ripple is present in the input current due to 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.6.

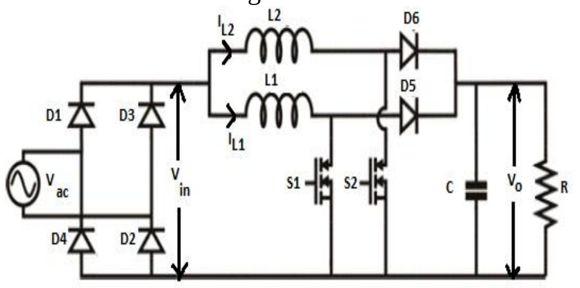

Fig.6. Interleaved boost converter

In interleaved boost converter two boost converters operate in 180˚ out of phase. The input current is the sum of two inductor currents I_{L1} and I_{L2}. Because the two inductor ripple currents are out of phase 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:

$$\frac{dI_{L1}}{dt} = \frac{V_{in}}{L1} \quad (3)$$

$$\frac{dI_{L2}}{dt} = \frac{V_o - V_{in}}{L2} \quad (4)$$

When switch S1 is off and switch S2 is on:

$$\frac{dI_{L1}}{dt} = \frac{V_o - V_{in}}{L1} \quad (5)$$

$$\frac{dI_{L2}}{dt} = \frac{V_{in}}{L2} \quad (6)$$

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

$$\frac{V_{in}}{L1} = \frac{V_o - V_{in}}{L2} \quad (7)$$

$$\frac{V_o - V_{in}}{L1} = \frac{V_{in}}{L2} \quad (8)$$

The above two equations i.e. equation (7) and equation (8) will be satisfied if and only if L1 = L2 and $V_o = 2V_{in}$.
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

At first simulation of single phase diode rectifier is performed. The MATLAB-Simulink model of single phase diode rectifier with filter capacitor is shown in fig.7.

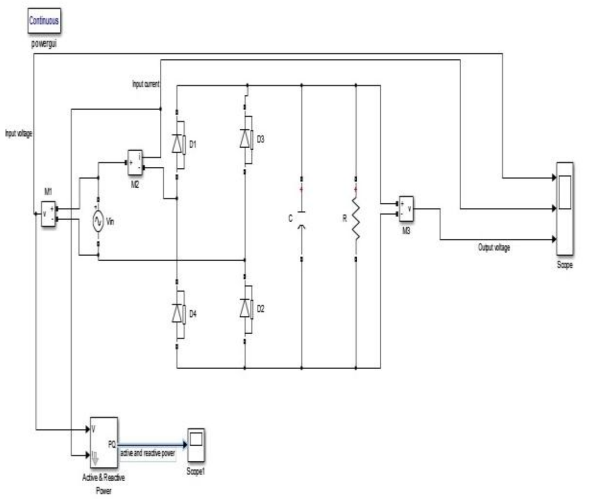

Fig.7. Simulation diagram of single phase diode rectifier

The waveforms are shown in Fig.8 and Fig.9.

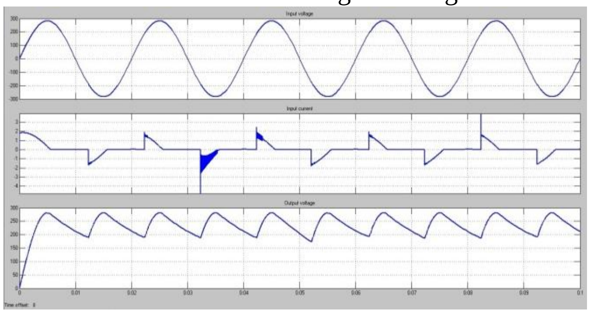

Fig.8. Input ac voltage, Input ac current and Output voltage waveforms

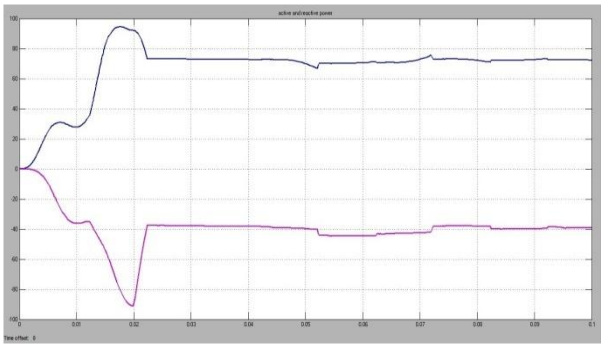

Fig.9. Active and reactive power waveform

From Fig.8 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.9. In this case the input power factor is 0.8756.

To improve the power factor boost converter is used. The MATLAB-Simulink model using boost converter is shown in Fig.10.

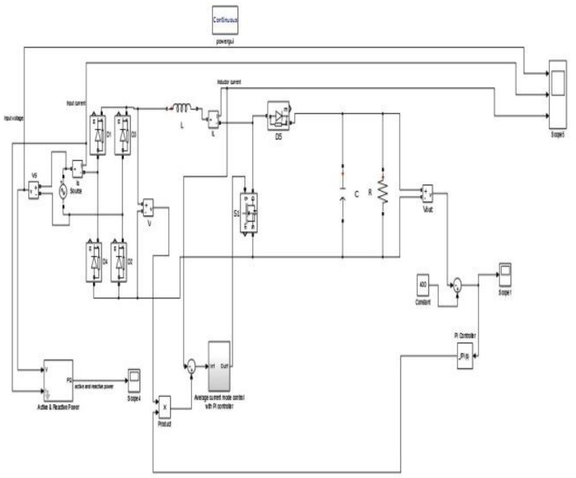

Fig.10. Simulation diagram using boost converter

The corresponding waveforms are shown in Fig.11 and Fig.12.

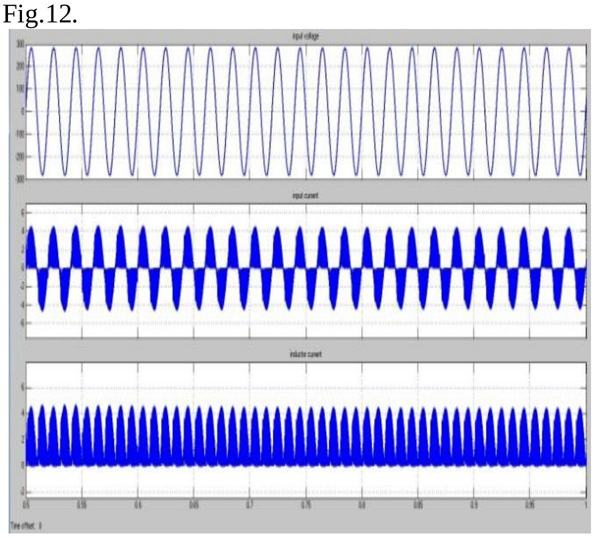

Fig.11. Input ac voltage, input ac current, inductor current waveforms

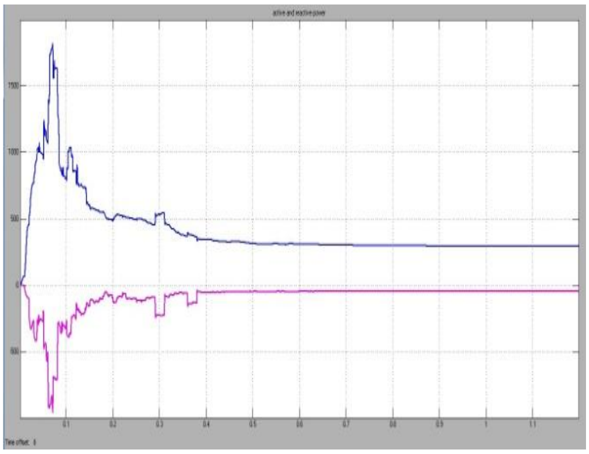

Fig.12. Active and reactive power waveforms

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 a lot. The power factor can be calculated by active and reactive power shown in Fig.12. In this case the input power factor is 0.9877.

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.13.

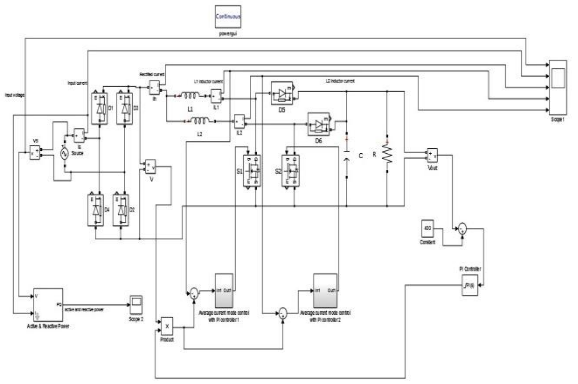

Fig.13. Simulation diagram using interleaved boost converter.

Here the input ac voltage is taken 200v (r.m.s.) and the reference output voltage is taken 400v to minimize the ripple of the input current. The corresponding waveforms are shown in Fig.14, Fig 15, and Fig.16.

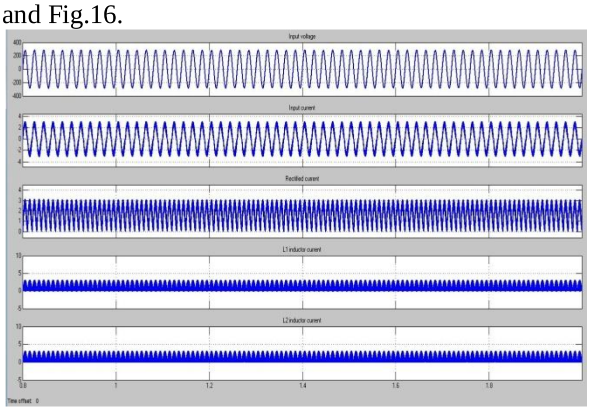

Fig.14. Input ac voltage, input ac current, rectified current, L1 inductor current, L2 inductor current waveforms.

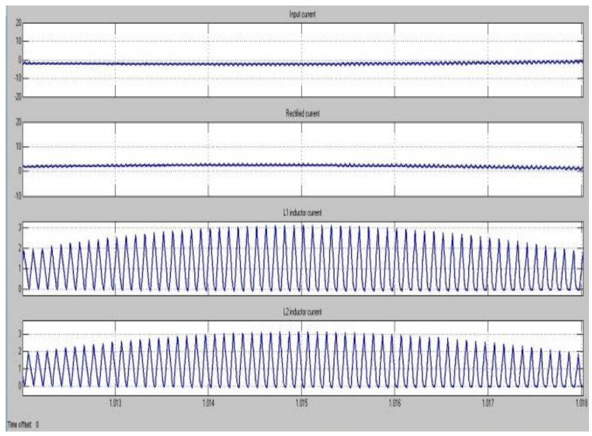

Fig.15. Ripples of input ac current, rectified input current, L1 inductor current and L2 inductor current

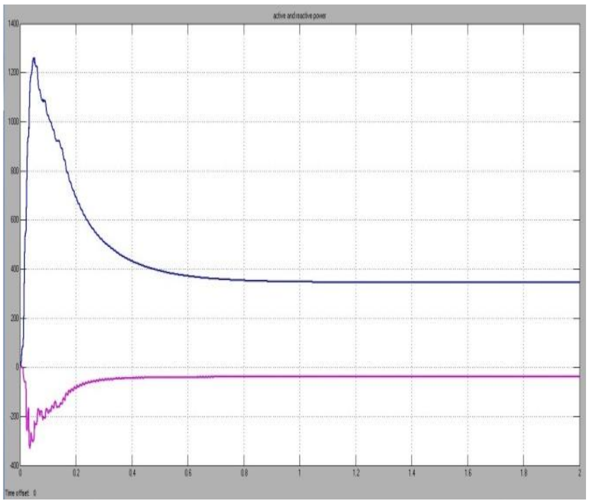

Fig.16. Active and reactive power waveforms

We can see in Fig.14 that the input current perfectly sinusoidal and from Fig.15 we can see that as two inductor currents are out of phase the input current ripple is almost eliminated. As a result the input power factor is improved a lot. The input power factor can be calculated from active and reactive power shown in Fig.16. In this case the input power factor is 0.9936.
The comparison of input power factor for different circuit topologies is shown in following table.

Table

Circuit topology	Input power factor
Single phase diode rectifier	0.8756
Boost converter	0.9877
Interleaved boost converter	0.9936

VIII. 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. The power factor may be further improved if fuzzy controller is used in place of PI controller.

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