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Power Factor Correction and THD Minimization by Interleaved Boost Converter in Continuous Conduction Mode

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ABSTRACT
The electrical energy available in the utility grid is not suitable for direct use in many applications. In particular, applications requiring DC source must involve an interface device between the AC power line and the load requiring the DC voltage. Conventional AC/DC conversion involves diode rectifiers with large capacitor to reduce DC voltage ripple. The filter capacitor reduces the ripple present in the output voltage but draws non-sinusoidal line current which reduces the power factor. So power factor correction (PFC) techniques are gaining increasing attention. 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. 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. Here average current mode controlled interleaved boost converter in continuous conduction mode using PI controller, is represented which provides high power factor and low THD.
***Keywords* –** Average current mode control, Interleaved boost converter, PFC, PI controller, THD.

I. INTRODUCTION

Now a days there are many appliances that requires DC power supply. So for obtaining this DC power, an interface must be provided between the AC power line and the load requiring DC voltage. Generally this conversion from AC to DC is done by single phase diode rectifiers.

These classical converters rectify the input ac line voltage to obtain DC output voltage, but this DC voltage oscillates between zero to peak. To reduce this ripple from DC voltage a filter capacitor is used, and that is where the problem of power factor and THD arises. The capacitor maintains the DC voltage at a constant value but it draws non sinusoidal current from the supply. The capacitor draws current from the supply only at the line voltage peaks. So the input current becomes pulsating which results in poor power factor and high THD. So the power factor correction techniques are gaining attention.

There are two types of power factor correction techniques, passive power factor correction and active power factor correction. Better power factor cannot be obtained by passive power factor correction techniques, and the output voltage also cannot be controlled. As a result active power factor correction technique is used for satisfactory result. In active power factor correction most popular is boost converter for its continuous input current.

The boost converter is widely used as active power factor corrector [1] because it draws continuous input current from the supply. This input current can be controlled to follow a sinusoidal reference using current mode control techniques.

There are different current mode control techniques [2], but best result can be obtained from average current mode control technique [3] due to its various advantages.

In this paper, power factor correction and THD minimization is done by two phase interleaved boost converter [4] whose input current is controlled by average current mode control technique. In this interleaved boost converter there are two boost converters operating in 180˚ out of phase [5]. So the ripple present in the current of boost converter gets almost eliminated and that is the main advantage of the interleaved boost converter. Here for average current mode control, PI controllers are used. The simulation of interleaved boost converter with PI controller is shown here to show that interleaved boost converter with PI controller provides good input current with high power factor and low THD. All the simulation is done by MATLAB-Simulink.

II. POWER FACTOR CORRECTION (PFC) TECHNIQUES

Power factor correction is a technique by which the degraded power factor of a power system can be improved by use of external equipments. Power factor correction can be classified into two types: passive power factor correction and Active power factor correction

In Passive PFC, only passive elements are used with the diode bridge rectifier, to make the line current sinusoidal. By using passive PFC, power factor cannot be increased to a desired value. With increase in the voltage, the PFC components increase in size. In passive power factor correction, the power factor can never be corrected to 1 and the output voltage cannot be controlled as well.

In active PFC there is control over the amount of power drawn by a load and power factor is close to unity. Commonly in any active PFC the input current of the load is controlled in order to make the current waveform follow the main voltage waveform closely (i.e. a sine wave). A combination of the reactive elements and some active switches are used to increase the effectiveness of the line current shaping and to obtain controllable output voltage.

III. BOOST CONVERTER AS ACTIVE POWER FACTOR CORRECTOR

Various converter topologies may be utilized for active power factor correction applications. Among these topologies, the boost converter topology (boost PFC topology) is utilized most frequently due to its advantages over other topologies. The main advantage of the boost PFC topology is its continuous input current which can be forced to track the diode bridge rectifier output voltage. In this type of power converter voltage obtained at the output stage is greater than that given at the input. The circuit diagram of a boost converter is shown in Fig.1.

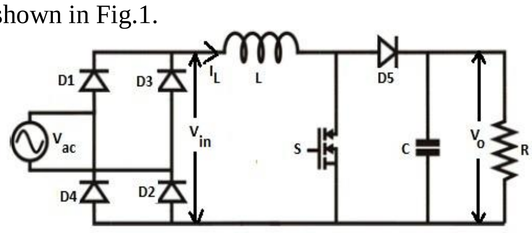

Fig.1. Boost power factor corrector

The inductor has this peculiar property to resist any change of current in them and that serves as the main principle which drives a boost converter. The inductor acts like a load when it is being charged and acts as a source of energy when it is discharged. The output voltage of boost converter is given by

$$V_o = \frac{V_{in}}{1-D} \quad (1)$$

Here D is the duty cycle.
When switch S is on:

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

Again when switch S is off:

$$\frac{dI_L}{dt} = \frac{V_o - V_{in}}{L} \quad (3)$$

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

IV. AVERAGE CURRENT MODE CONTROL USING PI CONTROLLER

There are different current mode control techniques to manipulate continuous input current obtained from the boost converter, however among them average current mode control provides the best result. In average current mode control the switching frequency is constant and it allows a good input current waveform. Average current mode control using PI controller is represented in Fig.2.

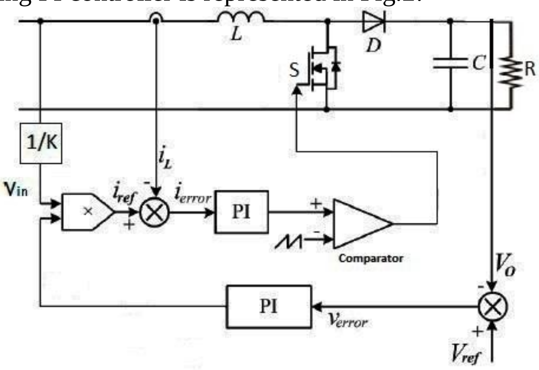

Fig.2. Average current mode control using PI controller.

Here for average current mode control voltage control loop and current control loop are used. Input current i_L is compared with the reference current i_{ref}. The current reference i_{ref} is obtained by scaling down the line voltage by a resistive divider with scaling factor K and multiplying it with the actuating signal obtained at the output of, voltage PI controller. This actuating signal is obtained by comparing the output voltage with reference voltage and passing the voltage error v_{error} through the voltage PI controller. The comparison of i_l and i_{ref} gives the i_{error} which has been amplified by another PI controller, and compared with the sawtooth wave, and provides the PWM drive signal for the switch S. The PI controllers consist of a proportional gain that produces an output proportional to the input error and an integration to make the steady state error zero.

When the inductor current i_L rises, the error current i_{error} decreases. On the contrary, i_{error} increases. When output voltage Vo increases, the output voltage error v_{error} decreases, error current i_{error} decreases. On the contrary, i_{error} increases.

V. PFC BY AVERAGE CURRENT CONTROLLED INTERLEAVED BOOST CONVERTER

Interleaving technique consists of a phase shifting of the control signals of cells in parallel operating at the same switching frequency. The main advantages are the current distribution and ripple reduction. The current in the switches are just a fraction of the input current. So interleaved boost converters can reduce input current ripple and the switching losses. The block diagram of the proposed system is represented in fig.3.

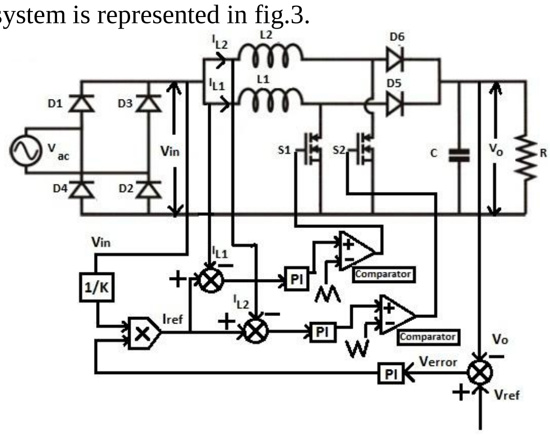

Fig.3. Interleaved boost PFC converter

Here for the power factor correction, a two phase interleaved boost converter is used. The continuous current drawn by the interleaved boost converter, is controlled using average current made control and for this purpose PI controllers are used. The average current mode control uses voltage control loop and current control loops.

For ripple reduction the two phases of interleaved boost converter operate in 180˚ out of phase. To obtain phase shift of 180˚ the output of the two current PI controllers are compared with two saw tooth waves that are 180˚ out of phase. In this way the PWM signals for the switches S1 and S2 are generated.

VI. SIMULATION AND RESULT

Here simulation of average current controlled interleaved boost converter using PI controller is performed for a system having output power of 1KW. The simulation is done in MATLAB-Simulink. The simulink model is shown in Fig.4.

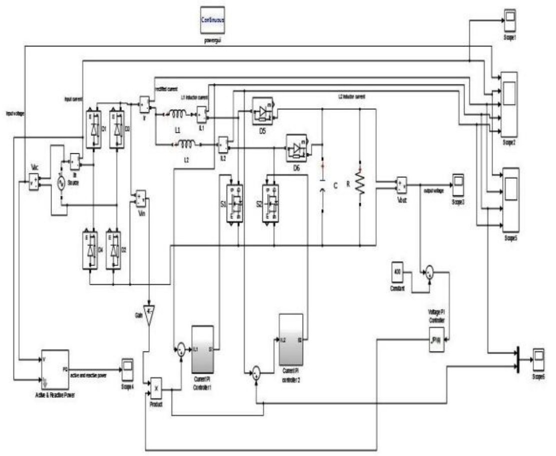

Fig.4. Simulink model of interleaved boost converter

Here the reference output voltage is taken 400v. So the output voltage curve is shown in Fig.5 to see whether output voltage is maintained at 400v or not.

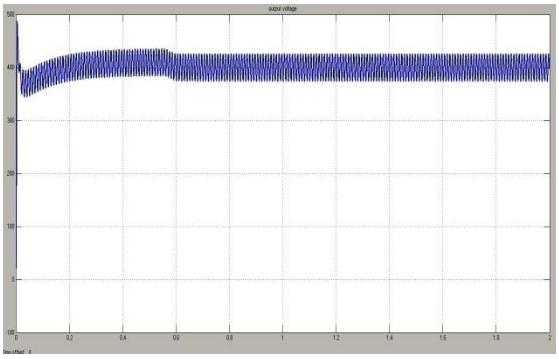

Fig.5. Output voltage waveform

So it can be seen that the output voltage is maintained at 400v. Now as described the inductor currents are controlled by average current mode control which is shown in Fig.6.

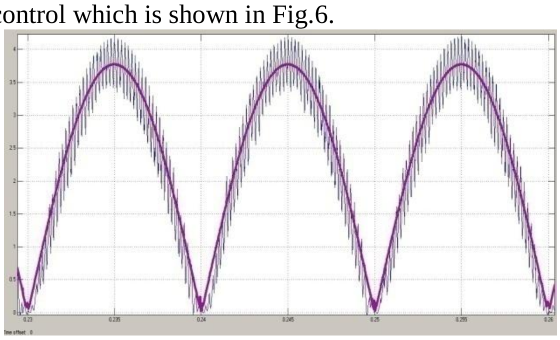

Fig.6. Average current controlled inductor current.

We can see that the inductor current follows the average current reference. Now the waveform of input voltage, input current, rectified current and two inductor currents is shown in fig.7.

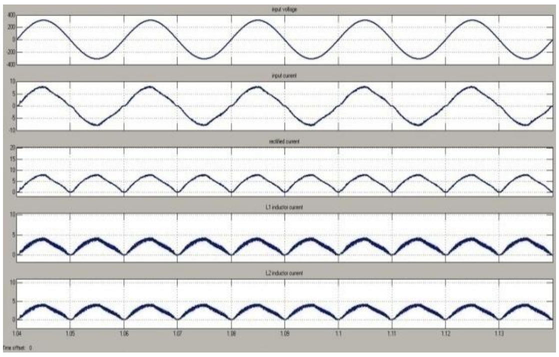

Fig.7. Input ac voltage, input ac current, rectified current, L1 inductor current, L2 inductor current waveforms.

As we can see from Fig.7 input ac current is almost sinusoidal as the input ac voltage. The input current is the summation of two inductor currents. As the inductor current ripples are phase shifted by 180˚ they cancel each other out. So the input current ripples are minimized. The input current ripple reduction is shown in Fig.8.

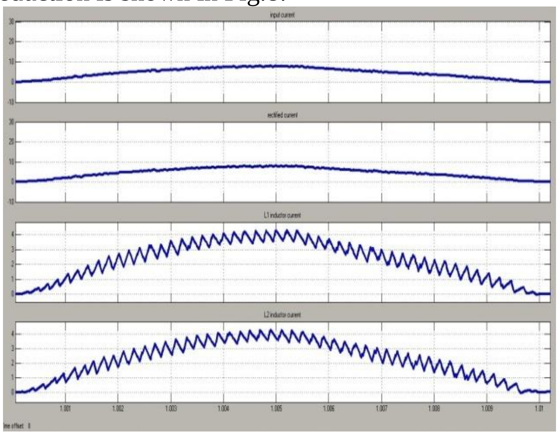

Fig.8. Ripples of input ac current, rectified input current, L1 inductor current and L2 inductor current.

So the interleaved boost converter provides ripple free good input current with high power factor and low THD. The power factor is calculated from the active and reactive power shown in Fig.9.

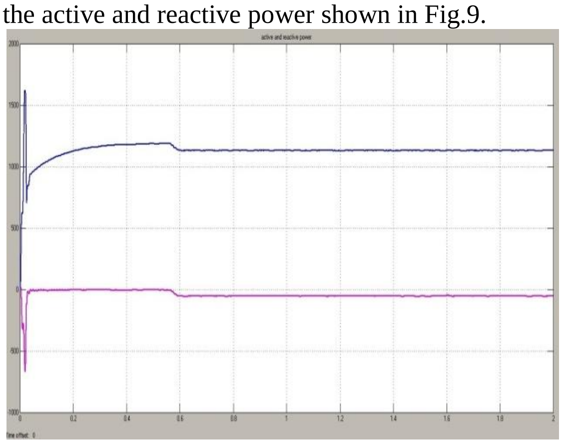

Fig.9. Active and reactive power waveforms

So from Fig.9 the active power obtained is 1130W and the reactive power is -55VAr.The power factor as calculated from active and reactive power waveforms is given by 0.9988 which is almost unity. Now the THD obtained of the input ac current is shown in Fig.10.

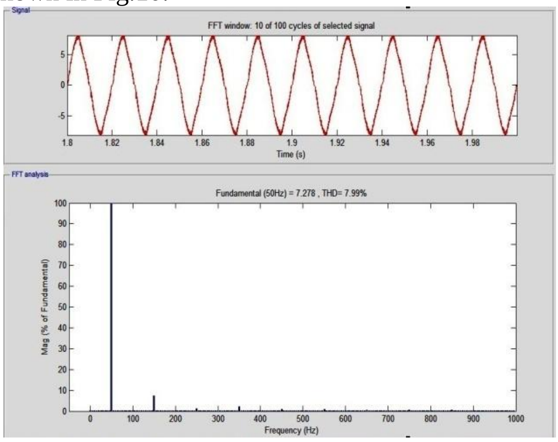

Fig.10. THD of input ac current.

The THD obtained of the input ac current is as low as 7.99%.

So the power factor = 0.9988 and

THD = 7.99%.

VII. CONCLUSION

Energy conversion is the main issue of the power electronics and widely applied in today's world. Also we cannot compromise with the power factor and THD. In this paper power factor correction and THD minimization by interleaved boost converter in continuous conduction mode, with average current mode control using PI controller, has been theoretically analyzed and simulated in MATLAB- Simulink. From the simulation result it can be concluded that using interleaved boost converter power factor has been improved a lot and THD has been minimized significantly. For further improvement fuzzy logic controller can be used in the place of PI controller.

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