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Power Factor Pre-regulator Using Constant Tolerance Band Control Scheme

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ABSTRACT

This paper presents operation and performance of a cost effective ac–dc current-controlled boost-type converter that provides input power factor correction and a near-sinusoidal input current waveform. The power factor correction converter can reduce harmonic pollution and disturbance on the supply mains. In the proposed scheme the input current can be sinusoidally shaped to follow the input voltage. The current mode controller essentially forces the envelope of the input current to vary sinusoidally, and a feedback circuit adjusts the amplitude. As a result, the current distortion factor approaches unity, and the harmonic pollution is also reduced. The size of the capacitor is reduced to almost 1/3rd and output dc voltage is stabilized to a nearly constant value for large variations in the line voltage.

Keywords: - Active and Reactive Power, Boost Converter, PFP, PWM

INTRODUCTION

Many existing power converters and motor drive systems draw non-sinusoidal input current from the AC supply mains. For example, a Boost Converter load draws a non-sinusoidal current from source, causing a reactive power at the source, i.e. the source voltage and current are out of phase.

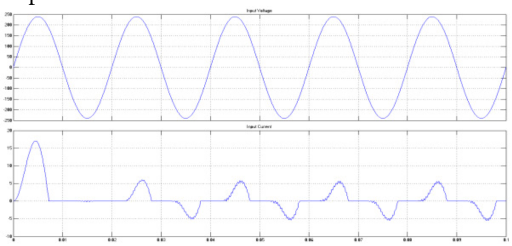

Figure-1 Effect of a Boost converter load on input current from ac supply mains (making it non-sinusoidal).

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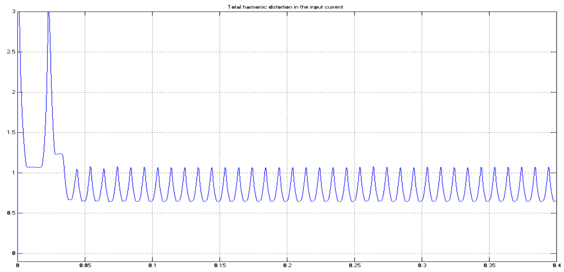


Figure 2 Total harmonic Distortion in Input Current in Input Current as a result of Boost converter.

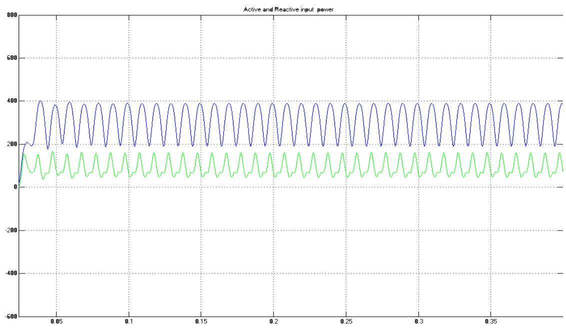


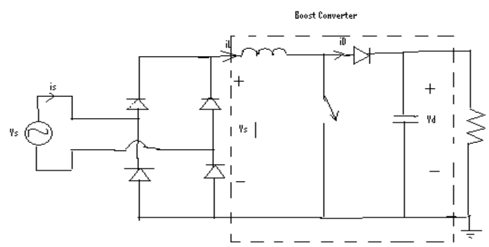
Figure-3 Active and Reactive Power in source as a result of Boost Converter load

The classical ac–dc rectification approach of using a full-wave diode bridge followed by a bulk capacitor is unsuitable because of the undesirable input current harmonic content. Normally, a large capacitor bank of thousands of micro-Farad is required. The large capacitor bank not only increases the size and weight of the converter equipment, but also the equipment cost.

In this paper, primarily a cost effective single phase power factor correction scheme using a continuous-mode boost converter is designed and examined. Its potential for power factor correction is explored. It will be shown that, by the use of a simple control method, this converter can provide *power factor correction* efficiently. The *current distortion factor approaches unity* and the converter operation can *reduce harmonic* *pollution*. Since, a boost converter has been used the overall energy efficiency in the system is quite high. Because of the power factor correction feature, the proposed circuit can meet new international harmonics standard.

Circuit Analysis

In essence, ac-dc converter in the power factor correction emulates a resistor. The resistor emulator, also called the Power Factor Pre-regulator (PFP), is basically a dc-dc converter.
Thus two separate control loops are required. The output voltage is sensed with a dc reference, and the error signal is used to modify the pulse rate of the switching device in the PWM converter. In the other loop, the output current is sensed, compared with the sinusoidal reference, and the error is used to control the pulse rate. These two loops are merged into one and called the current-mode control.
Because the input current to the step-up converter is to be shaped, the step-up converter is operated in a current-regulated mode. The feedback control is shown in a block diagram form in fig 4(c) and fig 4 (d), where i^*_L is the reference or the desired value of the current i_L in Fig. 4(a). Here i^*_L has the same waveform as $|v_s|$, (in Fig.1 (a)), by means of a resistive potential divider and multiplying it with the amplified error between the reference value V^*_d and the actual measured value of V_d. The status of the switch in the step-up converter is controlled by comparing the actual current i_L with i^*_L using ***Constant Tolerance Band Control*** scheme.
(a)



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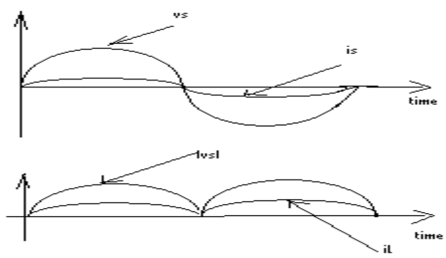

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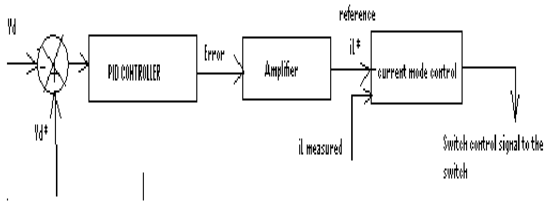
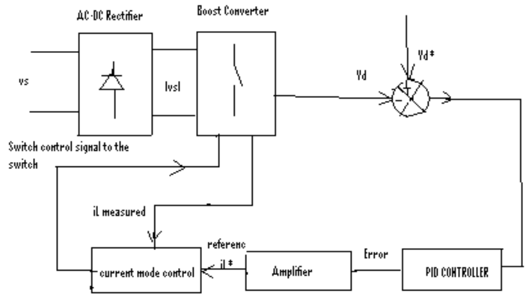


(c)



(d)
Fig-(4) Active harmonic filtering: (a) step-up converter for current shaping; (b) line waveforms and; $|v_s|$ (rectified source voltage); il (inductor current) (c) Control block diagram (d) Block Diagram Representation of Power Factor Pre-regulator

Since the switching frequency is very high in comparison to the line frequency, the input and output voltages of the Power Factor Pre-Regulator (PFP) may be considered to be constant throughout the switching period. Thus, the PFP converter may be analyzed like a regulator dc-dc converter. The line voltage and the input voltage to the PFP are given by:

$v_s = V_s \sin\theta$

$v_1 = |Vs| = Vs\ |\sin\theta|$ Equation-1

$\theta = 2\pi f_L t$

θ is the line phase angle.

The voltage transfer ratio of PFP is required to vary with the angle θ in a half line period. The voltage transfer ratio of the PFP is:

$$T_{vv}(\theta) = V_0(\theta)/V_s(\theta) = V_0/ Vs\ |\sin\theta| \quad \text{where } f_s >> f_L$$

Equation-2

Where, V_0 is the local average dc output voltage from the PFP. The high voltage transfer ratio can be achieved by using boost, buck-boost or fly-back topologies. Buck topology cannot provide high voltage transfer ratio.

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For Unity Power Factor

The current from the diode bridge must be identical in shape and in phase with the voltage waveform, hence,

$i_L = I_s \mid \sin\theta \mid$ Equation -3

The input and the output powers, average over a switching period are given by:

$p_1 = v_1 i_L = V_s I_s \sin^2\theta$,

$P_0 = V_d\, i_{load}$

Equation-4

Assuming the conversion ratio to be 1 ($P_i = P_0$), the output current requirement is determined as

$i_{load} = (V_s I_s \sin^2\theta)/ V_0$

Equation -5

The input and the output powers, as averaged over the line period, are:

$P_i = V_s I_s/2$,

$P_o = V_d I_0$ Equation -6

Where, I_0 is the average dc output current from the PFP.

The output current of the PFP is then

$I_{load} = 2\, I_0 \sin^2\theta = I_0(1\text{-}\cos 2\theta)$ Equation-7

Constant Tolerance Band Control Scheme

The Constant Tolerance Band Control Scheme provides instantaneous current control. The current is controlled within a narrow band of excursion from its desired value in hysteresis controller.

The hysteresis window determines the allowable or present deviation of current, Δi. Figure-5 below shows the desired current and actual current with hysteresis windows.

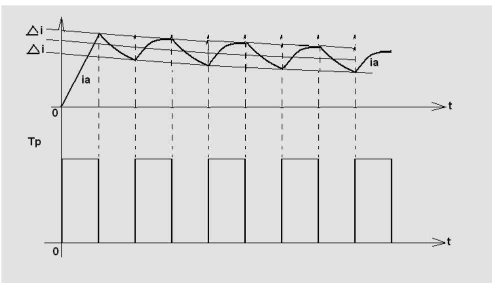

Figure-5 Constant tolerance band control scheme

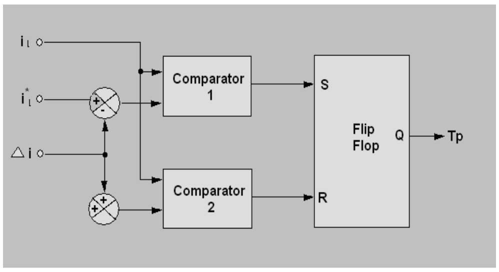

Figure-6 Realization of constant tolerance band controller. The logic is determined by –

$i_l \geq i_a^* - \Delta i$ $\quad T_p = K$

$i_a \geq i_a^* + \Delta i$ $\quad T_p = 0$

Equation-8

Design of PFP Using Constant Tolerance Band Control Scheme

The power factor pre-regulator was designed as shown in figure-4 using constant tolerance band control scheme. The results obtained have been shown below.

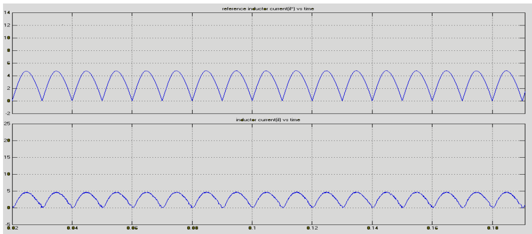

Figure-7

Waveform-1: inductor current (il) vs. time.

Waveform–2: reference inductor current (il*) vs. time

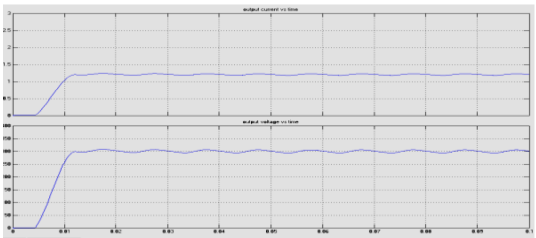

Figure-8 Output parameters of Boost Converter

Waveform -1: Load current vs. time

Waveform –2: Load Voltage vs. time

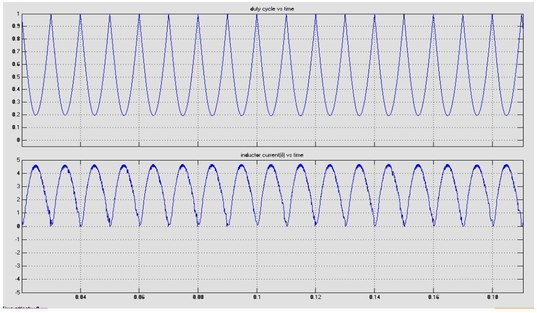

Figure-9
Waveform -1: duty cycle vs. t
Waveform – 2: il* vs. t

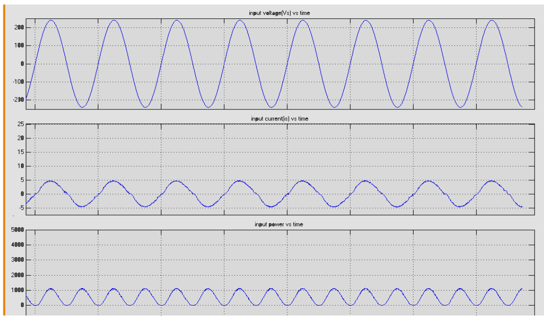

Figure-10
Input parameters after active current shaping
Phase Lag = 0 degree
Waveform- 1: Input Voltage
Waveform - 2: Input Current
Waveform - 3: Input Power

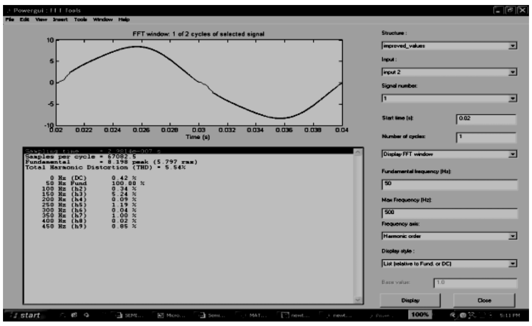

Figure-11 FFT analysis of input current of the system shows **THD** =5.54%

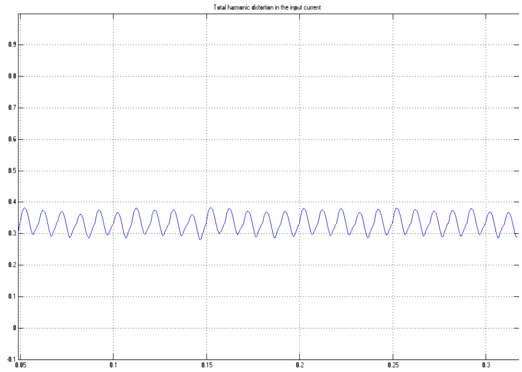

Figure-12 Total Harmonic Distortion in input current of the system (maximum value 0.36)

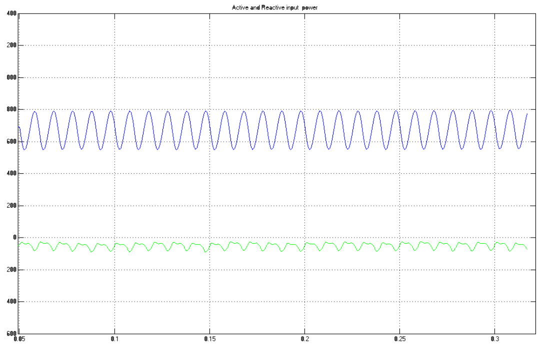

Figure-13 Input Active and Reactive power

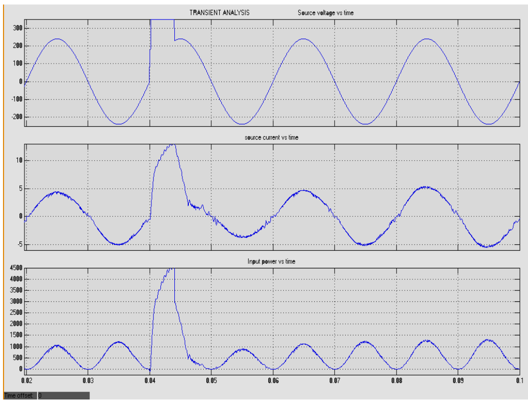

Figure-14 Transient Analysis of Power Factor Pre-regulator

Calculations

Specifications: The operating requirements for the active power factor corrector are as given below.
Pout (max): 250W
Vin range: 80-270Vac
Line frequency range: 47-65Hz
Output voltage: 400Vdc

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Switching frequency = 10 KHz

Inductor selection:
A. Maximum peak line current. Pin = Pout (max)

$$Ipk = \frac{\sqrt{2} \times Pin}{Vin\ (min)}$$ Equation-9

Therefore,
Ipk=1.41 x250/80=4.42 amps

B. Ripple current.
ΔI = 0.2 x Ipk
Δl = 0.2x4.42 = 0.9 amps peak to peak

C. Duty factor at Ipk where
Vin (peak) is the peak of the rectified line voltage at low line.

$$D = \frac{Vo - Vin\ (peak)}{Vo}$$ Equation-10

Thus, D= (400-113)/400=0.71

D. Calculation of Inductance

$$L = \frac{Vin \times D}{fs \times \Delta I}$$ Equation-11

L= (113x.71)/ (10,000x0.9) =4.5mH Round up to 5.0mH.
fs is the switching frequency.

4. Selection of output capacitor.
At is the hold-up time in seconds and V1 is the minimum output capacitor voltage.

$$Co = \frac{2 \times Pout \times \Delta t}{Vo^2 - V1^2}$$ Equation-12

Co= (2x250x34msec)/ (400-350) =450uF.

Calculation Of Efficiency

Voltage input to Boost Converter=Output Voltage of bridge rectifier= 14.5 V
Current input to Boost Converter=0.21 A
Thus, Input power = 0.21* 14.5 = 3.045 Watt
Output Voltage of Boost Converter = 30 V
Load resistance =300 ohm.
Output current of boost converter = 30/300 = 0.1 A
Thus, Output Power = 300 * 0.1 = 30 Watt
Therefore, efficiency of the power factor pre-regulator is
= (Output power) / (Input Power) = 0.98

Conclusion

A power factor pre-regulator using a dc–dc power converter is presented. In fig 10(a) and 10(b) we observe that the input current has been nearly shaped to input voltage. This is also proved by the input power waveform (fig10© & fig (13)), which shows that the power being generated is by large nearly active. Hence, the system ***emulates a resistor*** i.e. the power factor is nearly ***unity***. The pre-regulator has the following additional advantages:

- The ***Total Harmonic distortion*** in the input current has been reduced to 0.36 (figure-12).
- Since V_d is stabilized to a nearly constant value, the volt-ampere ratings of the semiconductor devices in the converter fed from V_d are significantly reduced (figure-8).
- Because of the absence of large peaks in the input current, the size of the EMI filter components is smaller.
- For the equal ripple v_d, only one-third to one-half the capacitance C_d is needed compared with the conventional circuit, thus resulting in a reduced size.
- Efficiency of the converter is found to be 98%.

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