An Improved Performance of Power Factor Correction Circuits with Average Current Control Approach

C. Brahmananda Babu, D. Lenine and Chintapalli. K. Sudhakar

***Abstract:* This paper presents active power factor correction method with constant switching frequency. The boost converter is used in the average current mode control. The inner loop has a current error amplifier which improves the power factor by properly shaping the input current in accordance with its reference. This reference signal is always synchronized and proportional to the line voltage hence the input current comes in phase with the input voltage. Thus by improving the power factor and maximum active power can be delivered to the load. This work presents average current mode control for the different values of boost inductance the power factor and total harmonic distortion is varying improved with constant switching frequency. The simulation results are verified through MATLAB simulink.**

***Keywords:-* Modeling of DC-DC Boost Converter, average current mode control, power factor correction and simulation results.**

I. Introduction

AC-DC converters are used extensively in the areas of switch mode power supplies, automation, uninterruptable power supplies etc. Due to non-linearity of the converter, it has low power factor and introduces harmonics in the line side. So power factor correction is necessary to convert the ac voltage to dc voltage and also to keep a high power factor. The equipment that supplies nonlinear loads causes disturbances in the main network and leads to the introduction of harmonics in power lines. All rectified AC sine wave signals with capacitive filtering draw high amplitude current pulses from the mains that will lower the power factor. In order to achieve unity power factor, many control methods are explored like Average current mode control, peak current mode control, hysteretic current mode control, nonlinear current mode control, border line current mode controlled etc. All these control methods have been implemented by analog circuits. Several commercial integrated circuits for current mode control are available for the power factor correction applications. The principle of the average current mode control is presented in section II. Modeling of control block diagram is presented in section III. Mathematical analysis is presented in section IV. Simulation results are presented in section V.

II. Boost Converter with Average Current Mode Control Topology

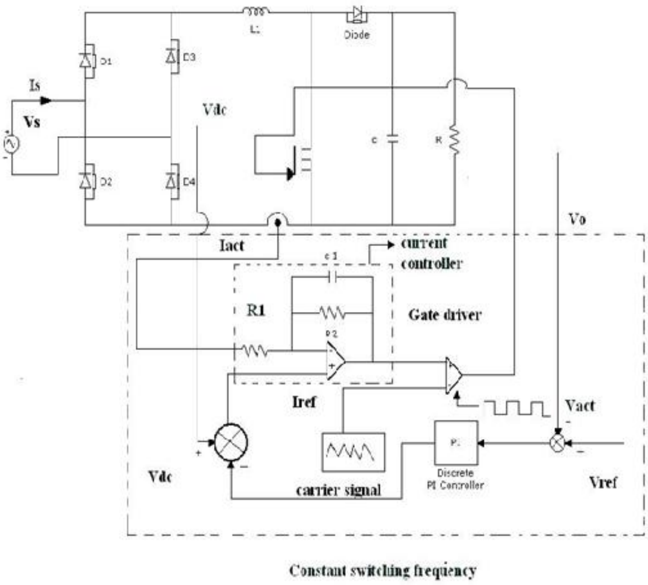

Fig. 1 Circuit Configuration of PFC Converter with ACMC.

In the average current mode control the block diagram and control circuit diagram is shown in the below.

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III. Modeling of Control Block

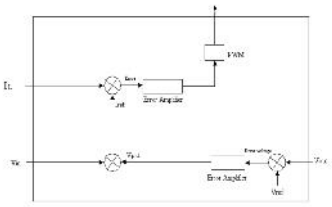

Fig 2. Block Diagram of Control circuit

The average current mode control the control circuit consists of two parts. They are:

- Feed forward/current control loop
- Feedback /voltage control loop

A. Current Control Loop:

The purpose of the current control loop is to force the current waveform to follow the shape of the voltage waveform. In order for the current to follow the voltage, the internal current amplifier has to be designed to capture enough of the harmonics of the output voltage using external capacitors and resistors. Once designing this it uses information from the gain modulator to adjust the PWM control that controls whether the power MOSFET is switched on or off. The heart of the PFC controller is the gain modulator. The gain modulator has two inputs and one output. The left input to the gain modulator block is called the inductor current (IL). The reference current is the input current that is proportional to the input full-wave-rectified voltage. The other input, located at the bottom of the gain modulator, is from the voltage error amplifier. The error amplifier takes in the output voltage (using a voltage divider) after the boost diode and compares it to a reference voltage. The error amplifier will have a small bandwidth so as not to let any abrupt changes in the output or ripple erratically affect the output of the error amplifier. The gain modulator multiplies or is the product of the reference current and the error voltage from the error amplifier (defined by the output voltage).

B. Voltage Control Loop:

The gain modulator and the voltage control loop work together to sample the input current and output voltage, respectively. These two measurements are taken and then compared against each other to determine if a gain should be applied to the input of the current control. This decision is than compared against a sample of the output current to determine the duty cycle of the PWM.

IV. Mathematical Analysis

A boost PFC circuit consists of a main power circuit and a control circuit as known in Fig 2 and 3. The main feature of this system is the presence of an output bulk capacitor in the main circuit and using a multiplier and two control loops feedback and feed forward, in control circuit. These features make the PFC converter highly nonlinear and many nonlinear behaviors are possible in this system. The main power circuit is constructed of full diode-bridge circuit followed by DC/DC boost converter. The basic circuit of the converter consists of inductor L, diode D, switch Q, and capacitor C connected in parallel to load R. The switch Q and the diode D are always in complementary operating states during the continuous conduction-mode CCM operation. The known average state space equations for boost converter are:

$$L\frac{di_L(t)}{dt} = -(1-d)v_o(t) + v_{in}(t) \quad (1)$$

$$C\frac{dv_O}{dt} = (1-d)i_L(t) - \frac{v_0(t)}{R} \quad (2)$$

Essentially, it is a typical current programmed boost converter, with the inductor current iL chosen as the programming variable and the programming template iref being proportional to the input voltage waveform. Obviously the average input current is programmed to track the input voltage, and hence the power factor is kept near unity.

The reference current is generated as:

$$v_{error} = v_{ref} - v_{out} \quad (3)$$

Where, V_{out} is the feedback voltage. This feedback voltage is obtained across the load.

The average-current-mode control is based on the error current to force the sensed inductor current to be equal to the reference current i_{ref} as:

$$i_{ref} = v_{in} * v_{pid} \quad (4)$$

Where V_{pid} is the amplified error voltage and V_{in} is the output of diode bridge.

Current error is obtained by tracking the inductor current and comparing with the reference current.

$$i_{error} = i_L - i_{ref} \quad (5)$$

This error voltage is amplified through current error amplifier to generate the reference signal for Pulse Width Modulation (PWM).

V. Simulation Results

Simulation is performed by MATLAB to verify the boost converter with average current mode control. In the average current mode control the Analytical evaluation of various input voltage the power factor decrease and the total harmonic distortion is increase and the table.1 is shown below. In the average current mode control current various boost inductor values the power factor increases and the magnitude inductor current is increases and table.2 is shown below. Input voltage is (90-150)V, R=320 Ohm, L=2.3e-3H, C=1200*uF* and switching frequency is 50 kHz.

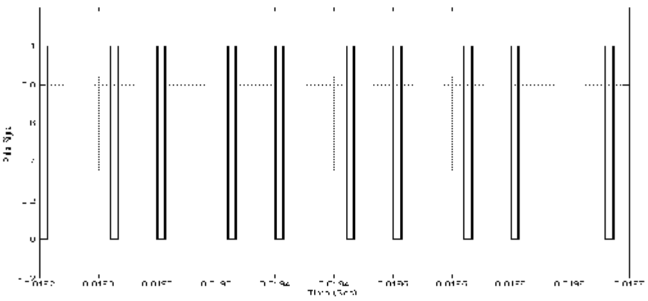

Fig.3 Response of Gate Signal

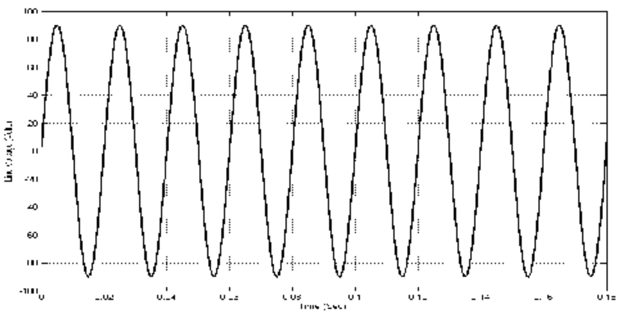

Fig. 4 Line Voltage at 90Volts

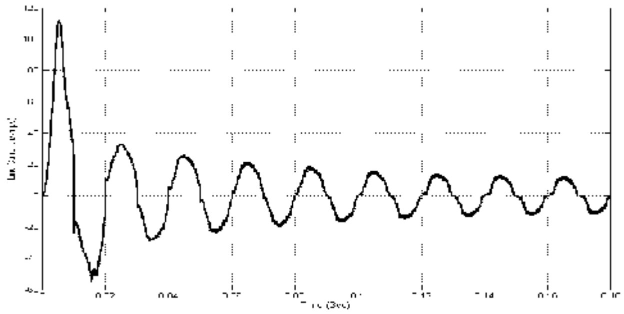

Fig.5 Waveform of Line Current

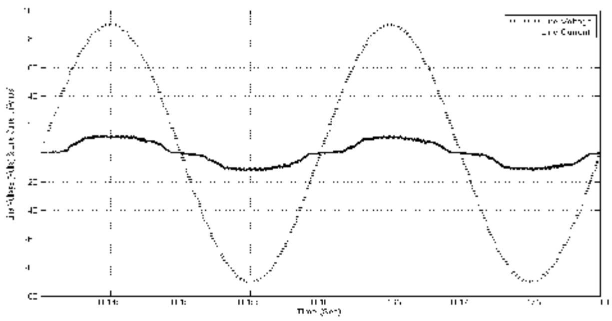

Fig.6 Waveform of Line Voltage and Line Current

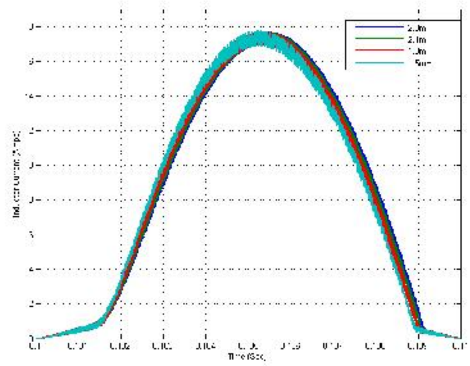

Fig.7 Response of Various Inductor Current at different boost inductor.

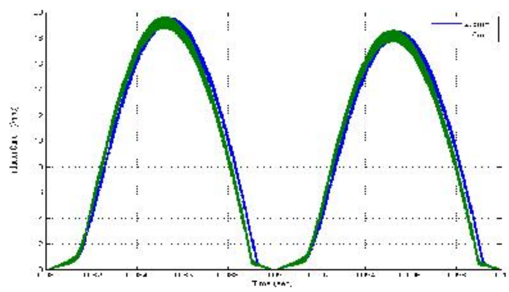

Fig.8 Waveform of High value of inductor current and Low value of inductor Current.

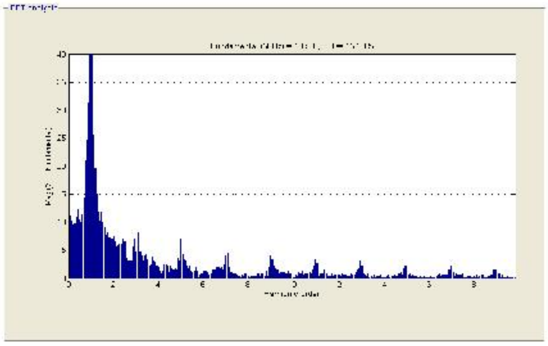

Fig.9 Harmonic Spectrum of Line current at 90 Volts

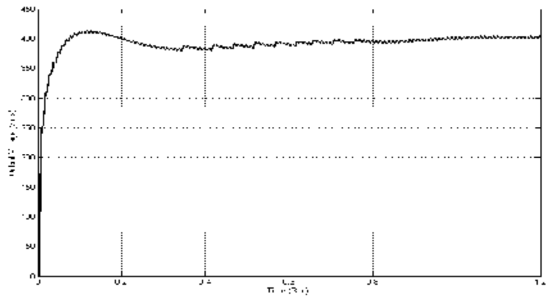

Fig.10 Response of output voltage

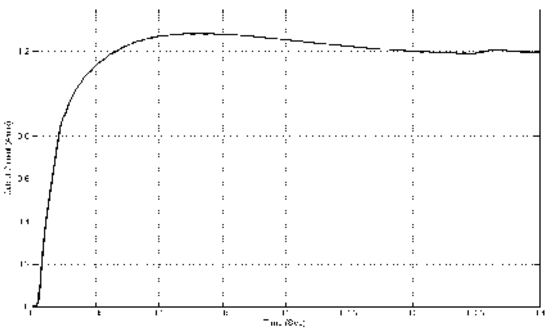

Fig.11 Response of output current.

Table.1

Analytical Evaluation of Various Input Voltage at Fixed Load (320Ohms)

INPUT VOLTAGE (Volts)	POWER FACTOR	THD (%)	OUTPUT	
			VOLTAGE (Volts)	CURRENT (Amps)
90	0.926	15.20	400	1.25
110	0.918	14.84	398.3	1.24
130	0.908	13.88	400.1	1.25
150	0.899	12.83	399.8	1.24

Table. 2

Magnitude of Inductor Current at Various Boost Inductor

Boost Inductance (H)	Power Factor	Magnitude Inductor Current (Amps)
1.5e-3	0.899	17.2
1.8e 3	0.908	17.5
2.1e-3	0.912	17.9
2.3e-3	0.916	18.2

From the Fig.3, gives the response of gate signal pulse waveform, which controls the power device for boost converter circuit. Simulation is performed by MATLAB /SIMULINK to verify the proposed control technique. Fig. 4 is the input line voltage of the PFC boost circuit under fixed load of 320 ohms at 90V. Fig. 5 as shows the response of line current of the PFC boost circuit at 90V input voltage. From the Fig.6 shows that, the line current nearly inphase with line voltage and also, it shows that power factor closer to unity (0.926). In this work clearly observed that power factor and magnitude inductor current at different values of boost inductance like 1.5mH, 1.8mH, 2.1mH and2.3mH and response of various inductor current as shown in Fig. 7. The high value of inductor current of 2.3mH and low value of inductor current of 1.5mH of the waveform as shown in the Fig. 8. The FFT analysis of the input current waveform of average current mode control is shown in Fig.9. It shows that current waveform has a fundamental component of 18.58A, with total THD of 15.20% under fundamental frequency 50Hz. Fig. 10 shows the output voltage of the rectifier circuit, it observed that the output voltage has settled around 400V for given line voltage is 90V. Fig. 11 to shows the output current rectifier circuit, it is clearly observed that the shape of the current waveform is similar to output voltage, because load has been resistive.

VI. Conclusion

The simulation results of average current control technique for various input voltage and boost inductor values, magnitude inductor current, total harmonic distortion (THD) and the power factor (PF) was calculated. The power factor is almost unity for the average control technique as comparatively open loop PFC Converter. The concept of switching frequency is constant in average current control is clearly shown and explained in the simulation results which support this work. The main objective of this work is fulfilled i.e. power factor correction has achieved nearly unity (0.926).

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