LPCM Controlled Single Phase AC/DC Converter for High power factor & Tight Voltage Regulation

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Abstract— The control technique presented in this paper - Linear Peak Current Mode Control (LPCMC) is a simplified power factor correction (PFC) technique for single stage AC/DC converters, Which has the following advantages: there is no multiplier and voltage sensing circuits, By using low cost standard PWM control IC's implementation becomes easy for this controller. In this paper Integrated buck-flyback converter (IBFC) is a single stage AC/DC converter, operating in discontinuous conduction mode(DCM) to achieve high Power factor with fast output voltage regulation. Operating modes of IBFC is also presented. comparative analysis of voltage mode controller to linear peak current controller for 90-230V input, 48V Output and 200W ac-dc converter operating at 100 kHz is presented and MATLAB/SIMULINK is used for implementation and simulation results show the performance improvement of proposed controller.

Keywords- *Linear Peak Current Mode Control (LPCMC), Integrated buck-flyback converter (IBFC), power factor correction (PFC),voltage mode controller.*

I. INTRODUCTION

The primary tasks of a controller for PFC circuits are to:

- To achieve high power factor during steady-state operation with a constant load.
- Maintain an output voltage waveform with low ripple.

In case of the controller forces the input current wave to gain the same shape as input voltage when both above controls goals are achieved. Therefore the input impedence as if resistive, then the rectifier is known as a resistor emulator. The resistor emulator requires not only a near-unity power factor, but also low harmonic contents in the line current. The following 2 traditional approaches for controlling resistor emulator;

1. The voltage follower approach..
2. The multiplier approach.

The voltage approach is recognized resistor emulator with the constant duty ratio (or) it is also identified the constant on time control. The current sensor is not required to voltage mode pulse width modulation PWM chip because of it is simply control circuit. However, in the discontinuous operation the current stress will be very high on MOSFET and demands to reduce the current ripple to get low electromagnetic interference to the line.

The multiplier approach requires relatively complicated control circuitry[2]. This approach needs a multiplier, current sensor, sensor of the input voltage. The control method is based on the current mode control. The current reference is rectified line voltage with its amplitude modulated by the modulation voltage, the output of the feedback compensator. In contrast to the voltage-follower approach, resistor emulator with the multiplier approach operates in CCM. The shortcoming of this technique is the variable switching frequency.

The above shortcoming is overcome by using PWM Active Power factor correction techniques under *Current mode control*. In this approach, an additional inner control loop is to be used. The inductor current which, feeds the output stage as well as output voltage, and the control voltage controls it directly, In current mode control the current feedback from output stage and it is controlled directly.

In PWM power factor correction technique the power switching device operates at pulse-width-modulation mode. The switch is turned on at the instant when the pulse is high and the switch is turned off when the pulse is low. The turn off and turn on time depends on the carrier frequency waveform.

There are two basic controllers are proposed for the PWM power factor correction technique, namely, *Peak current mode control* [3] and *Average current mode control* [4] The PWM current-mode-control has many beneficial features such as [5]:

- It limits the peak switching current.
- It removes one pole..
- It makes easier the designing the circuit components
- It allows a modular design of power supplies by equal current sharing where several power supplies can be operated in parallel and provide equal currents, if the same control voltage is fed to all the module.
- It provides input voltage feed-forward. The current mode control the input voltage feed-forward is automatically accomplished with the proper slope compensation. Resulting in an excellent rejection of input line transients.

However, The peak current mode controller and average current mode controllers are suffering from the stability problem due to the presence of inherent sub harmonic oscillations if the duty ratio of the power switch is greater than 50% and noise immunity. This problem can be overcome by using the slope compensation technique. In slope compensation technique an additional ramp is added to the sensed inductor current. It increases the circuit complexity. In order to simplify the control scheme LPCM has been proposed in this paper.

In this paper comparative analysis of the IBFC with voltage mode control and LPCM for HPF offline applications is investigated. The important design characteristics such as bulk capacitor average voltage, bulk capacitor voltage ripple and currents, and voltages in the switches will be obtained. A universal input(90–230V)48V-output 200W ac–dc converter operating at 100kHz is designed to illustrate the application of the derived characteristic and evaluate the possibilities of this converter. In the following, Section II presents the offline operation of the IBFC. In Section III the analysis of the IBFC is presented, and the important design characteristics are derived. Section IV shows the converter control scheme. Section V design example of IBFC shows the. Section VI shows the MATLAB/ simulation of a 48V–200 W universal input converter and the Simulation results. Finally, conclusions are provided in Section VII.

II. OPERATION OF THE IBFC

The configuration of the IBFC when operated from an ac line is shown in Fig.1.This converter has already been proposed for other power applications but has not been analyzed for high power factor dc power supplies [6]. The equivalent circuits of the IBFC during a line-half period are shown in Figure 2. When the instantaneous line voltage is less than the bulk capacitor voltage, the rectifier bridges diodes are reverse biased and zero current flows through the buck inductance. Since line voltage is superior than the bulk capacitor voltage diodes Da and Dc are open. There fore no current flows through Dc and Da. Since instantaneous line voltage is superior than the bulk capacitor voltage diodes Da and Dd are also open during time intervals. The equivalent circuit shown in Figure 2(a). In this mode only flyback converter is operating through switch sw1 and diodes Db and Dd .When the switch is on Dd is reverse bias, when the switch is off Dd is forward bias. In this mode the bulk capacitor will supplies energy to the load. Figure 2(b) and (c) shows the equivalent circuits when the instantaneous line voltage is superior than the bulk capacitor voltage. In this mode the current starts increases in both buck and fly back inductances when the control switch sw1 is activated and also the current through the control switch is either buck or fly back inductor current. In summary the current distribution as follows, when $I_b > I_f$ current I_b will circulate through sw1,Da will handle the I_b-If, with Db being off. When $I_b < I_f$ the current I_f will circulate through sw1,Db will handle current $I_f - I_b$, with Da being off. In this mode when the switch is on Dd is off since reverse polarity of transformer and Dc is off since capacitor voltage is greater than the line voltage. Figure 2(c) shows the equivalent circuit when the line voltage is higher than the capacitor voltage and switch is open. During this interval, both buck and fly back inductors are being de energized, and the energy is supplied to the bulk capacitor and load, respectively. In this mode only diodes Dc and Dd will be conducting as long as energy is stored.

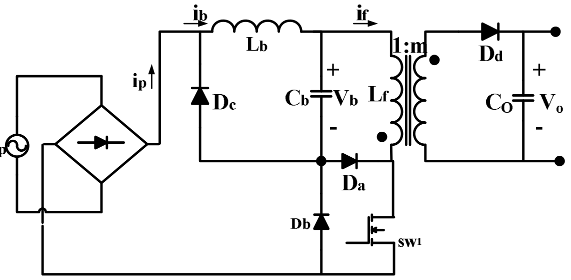

Fig.1 HPF Integrated Buck-Flyback Converter

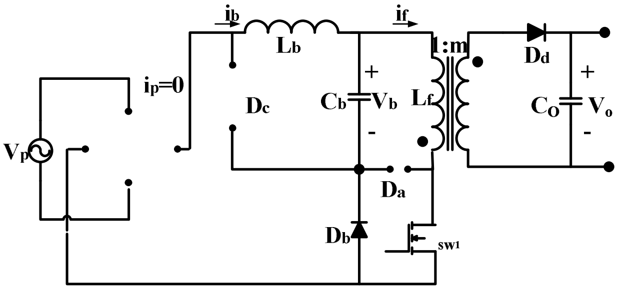

Fig . 2(a) $V_p < V_b$

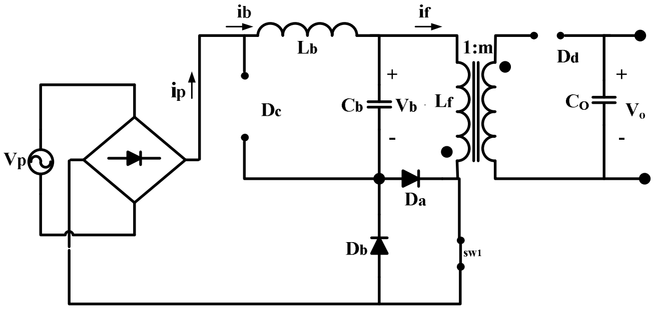

Fig . 2(b) $V_p > V_b$ *SW1 ON*

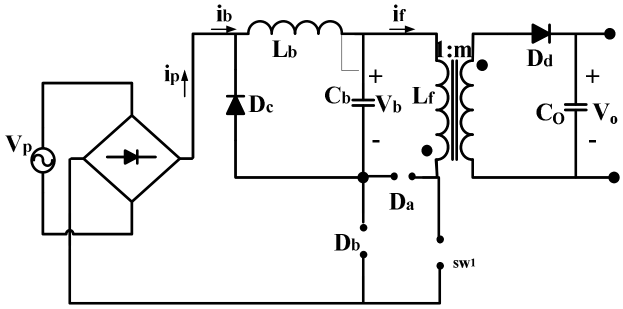

Fig . 2(c) $V_p > V_b$ SW1 OFF

Fig. 2. Operating Modes Of IBFC

III. ANALYSIS OF THE OFF-LINE IBFC

To derive the bulk capacitor voltage characteristic of the IBFC, Fig.3. Illustrates the equivalent circuit of the buck converter at a low frequency. The buck converter is loaded with the flyback converter, which is represented by its equivalent resistance R_F. Resistance R_b represents the equivalent resistance of the buck converter when operating in

DCM. It is well known that the values of these resistances are given as follows:

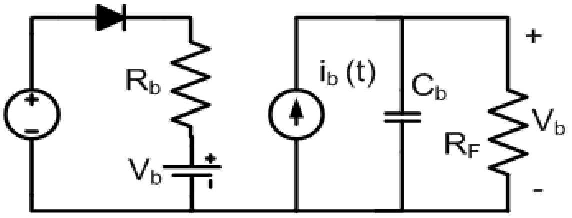

Fig. 3. Equivalent Circuit Of IBFC

$$R_b = \frac{2L_b f_{sw}}{\partial^2}, R_F = \frac{2L_f f_{sw}}{\partial^2} \tag{1}$$

Where f_{sw} is the switching frequency and ∂ is the duty cycle with which the control switch sw_1 is operated. In the circuit the instantaneous power consumed by the resistance R_b and the voltage source V_b is transferred to the output section formed by the filter capacitor C_b and equivalent resistance of the flyback converter R_F,from the circuit in Fig.3.the dc mean current I_B will circulate through the flyback equivalent resistance, thus giving a bulk capacitor voltage $V_b = I_b/R_F$.

Then, the following equation must be solved to obtain the voltage V_b:

$$V_b - i_b R_F = 0 \tag{2}$$

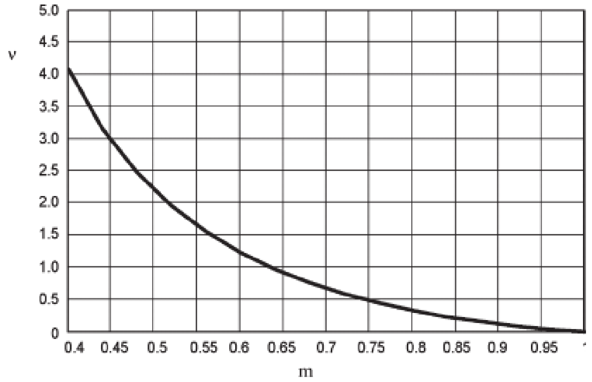

Fig. 4.Ripple Factor V as a function of the voltage ratio m

IV. CONVERTER CONTROLLER

LPCMC offers the following advantages: Elimination of the controller multiplier and input voltage sensing circuits, unconditional stability of the current loop, and ease of implementation using low cost standard PWM control IC‘s (e.g.UC2843). The control technique is based on designing a current loop whose static gain is linearly dependent upon the off duty-cycle of the switch as result, the static gain of the current loop is proportional to the input voltage, and the current loop inherently controls the inductor current. In this controller the output of the voltage error amplifier subtracts the compensation ramp which sets the reference current by multiplying a scaled gain. Fig. 5 Shows the Linear Peak Current Mode Controller[4].

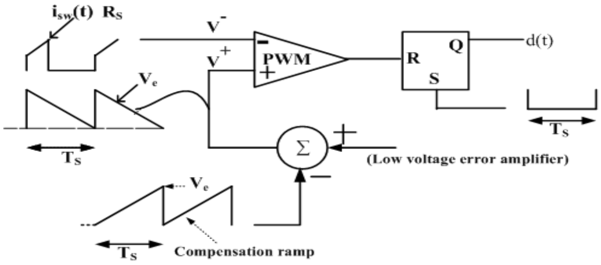

Fig.5 Linear Peak Current Mode Controller

$$I_c(t) = \frac{V_c(t)}{R_s}$$

$$= \frac{V_m}{R_s\left(1 - \frac{t}{T_s}\right)} \tag{10}$$

IV.DESIGN EXAMPLE

Design a Universal Power Supply that accepts a Single-Phase line voltage from (90-250V_{RMS}) at a Switching Frequency 100KHz, V_0=48V , I_0=4.2A. Assume the conduction angle θ=120 to Improve Power Factor.

$$m = \sin \frac{\pi - \theta}{2} \tag{3}$$

$$m = 0.5 \tag{4}$$

Since the Voltage ratio is 0.5, the bulk capacitor voltage at lowest line voltage is given by

$$m = \frac{V_b}{V_g} \tag{5}$$

$$0.5 = \frac{V_b}{\left(\sqrt{2}\right) * 90}$$

$$V_b = 63.63V \;. \tag{6}$$

Thus the flyback inductance is given by

$$p_0 = \frac{V_b^2 D^2}{2 L_f f_s}$$

$$200 = \left(63.63^2 * 0.5^2\right) / \left(2 * L_f * 10^5\right)$$

$$L_f = 25\mu H \tag{7}$$

The flyback turns ratio is given by equation,

$$D_{Flyback \;\max} = \frac{V_0}{nmv_g + V_0} \tag{8}$$

In order to have a maximum duty cycle of 0.5 at the lowest line voltage, the necessary turn ratio is obtained as *n* =0.75. Regarding the buck inductance, using the selected voltage ratio *m* =0.5 in , a value of the inductance ratio *α* =0.8 is obtained.

$$\alpha = \frac{L_b}{L_f}$$

$$\mathrm{L}_b = 0.8 * 25\ \mu$$

$$L_b = 20\mu H \qquad (9)$$

Finally, the design of the bulk capacitance is performed in this example based on the highest voltage ripple allowed. From Fig.4,a ripple factor ν =2.3 is obtained for the selected voltage ratio (m =0.5). The highest voltage ripple will rise at the lowest line voltage and full power. The highest voltage ripple selected in this design is20% at 90Vand 200W.It should be noted that the voltage ripple will be compensated by the closed-loop error amplifier; thus a very low voltage ripple is not necessary.

V. SIMULATION AND RESULTS

By using MATLAB/Simulink, IBFC is implemented using Voltage mode controller and LPCM. Fig.6 shows Matlab/ Simulink model of IBFC with Voltage mode controller Fig.7 , Fig.8,Fig.9 are input voltage and current, output voltage waveforms and output current without step change load. Fig.10 , Fig.11,Fig.12 are input voltage and current, output current and output voltage with step change load at 0.25sec. Fig.14 shows Matlab/ Simulink model of IBFC with LPCM controller Fig.17 , Fig.18,Fig.19 are input voltage and current, output voltage waveforms and output current without step change load. Fig.20 , Fig.21,Fig.22 are input voltage and current, output current and output voltage with step change load at 0.25sec.Fig.23,Fig.24 and Fig.25 are the input current and voltage ,output voltage and output current waveforms for LPCM controlled IBFC with 170V(AC)/48V(DC).

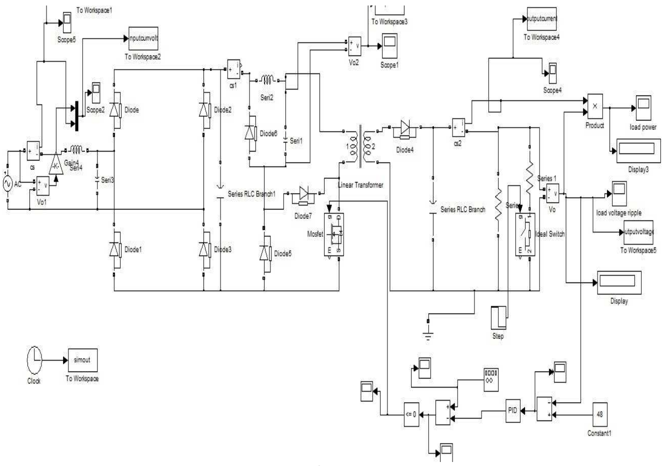

Fig.6 Matlab/Simulink model of IBFC with Voltage Mode controller

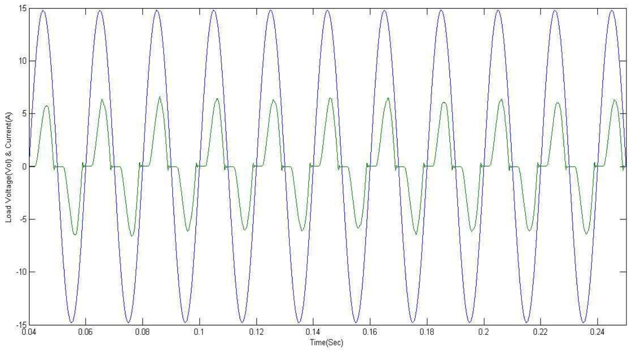

Fig. 7.Input Voltage(V) & Current(A)

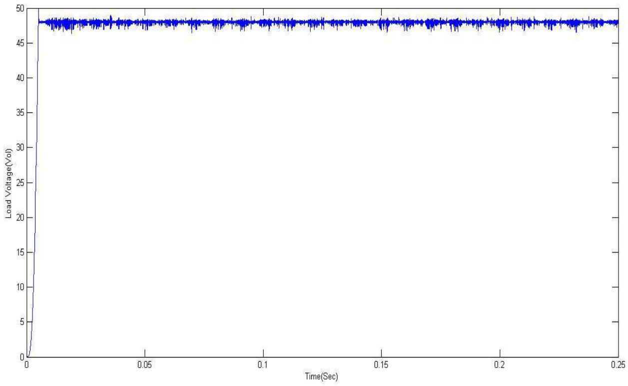

Fig. 8.Output Voltage(V)

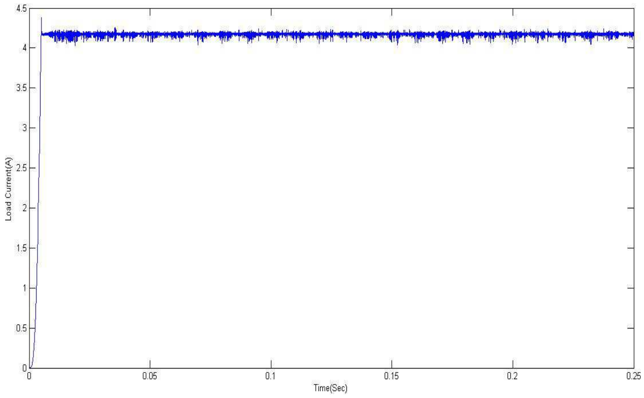

Fig. 9.Output current(A)

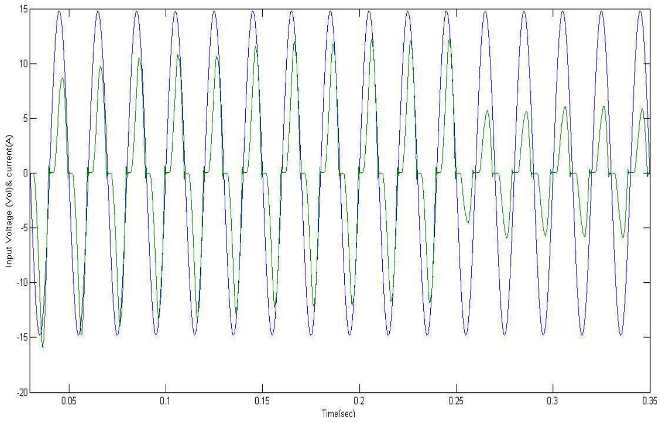

Fig. 10.Input Voltage(V) & Current(A) With Step Change of load at 0.25sec

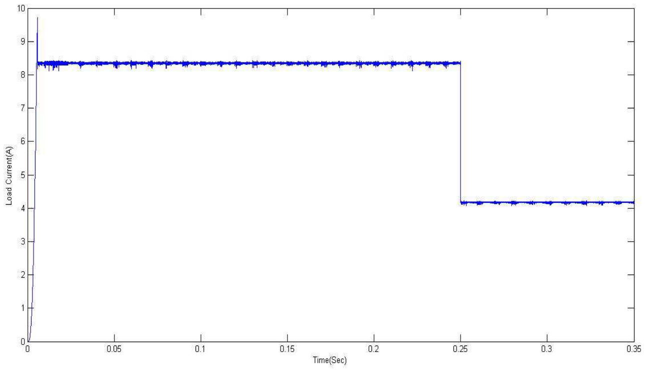

Fig. 11.Output Current With Step Change of load at 0.25sec

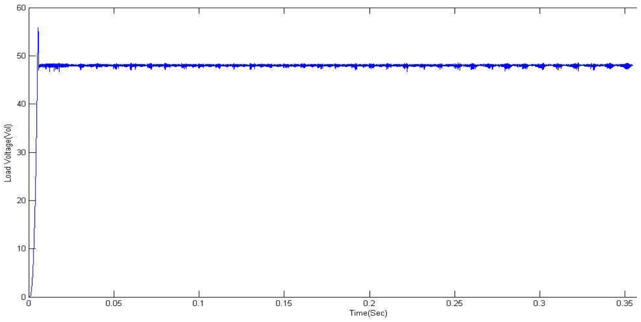

Fig. 12.Output Voltage(V) With Step Change of load at 0.25sec

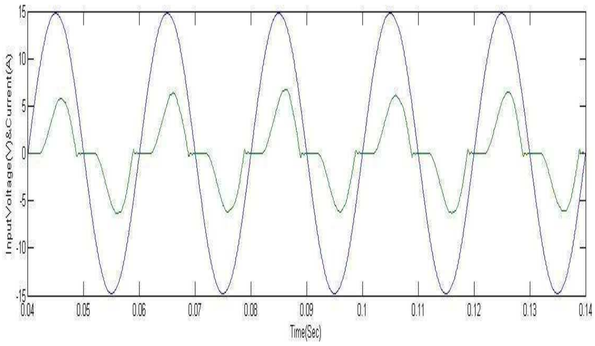

Fig .13 Input Voltage(V) &Current (A) for 230V, P.F =0.92.

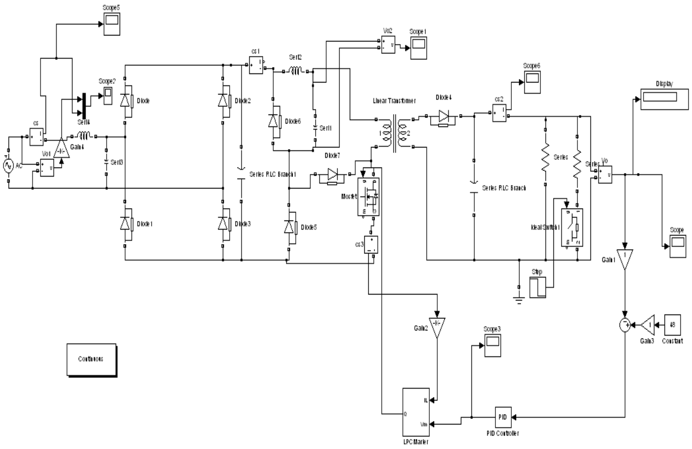

Fig.14. Matlab/Simulink model of IBFC with LPCM controller

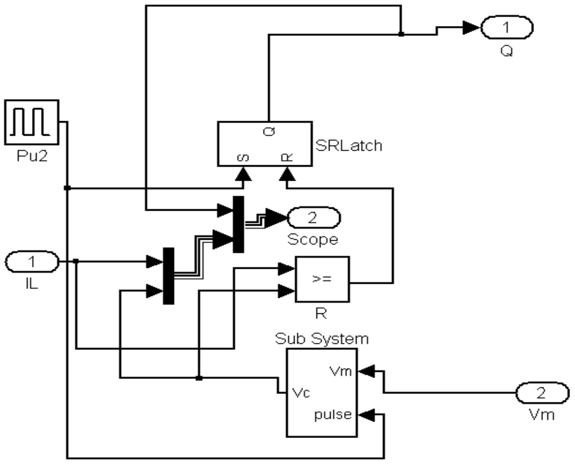

Fig15. Sub circuit of LPCM carrier

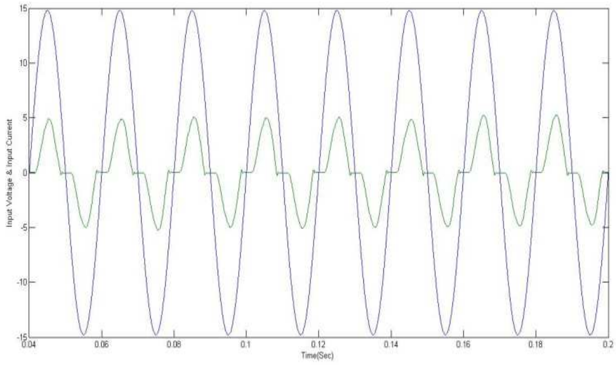

Fig. 17.Input Voltage(V) & Current(A) for 230V(AC)/48V(DC)

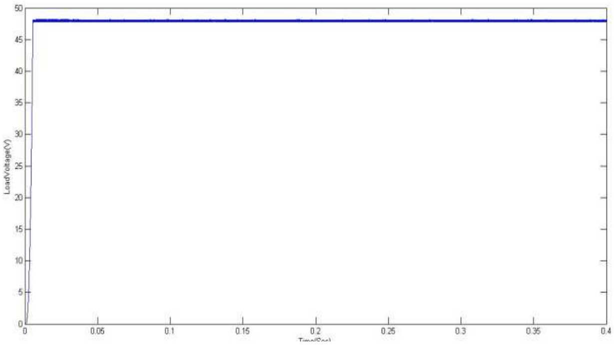

Fig18.Output Voltage (V) for 230V(AC)/48V(DC)

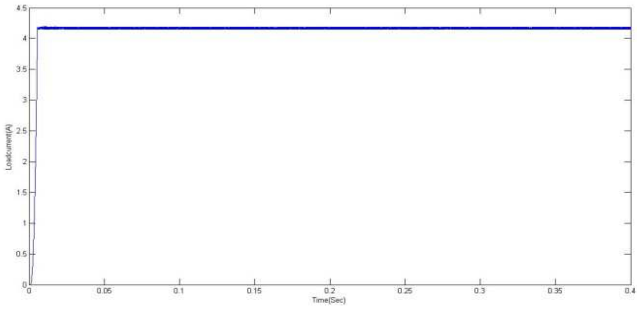

Fig19.Output current(A) for 230V(AC)/48V(DC)

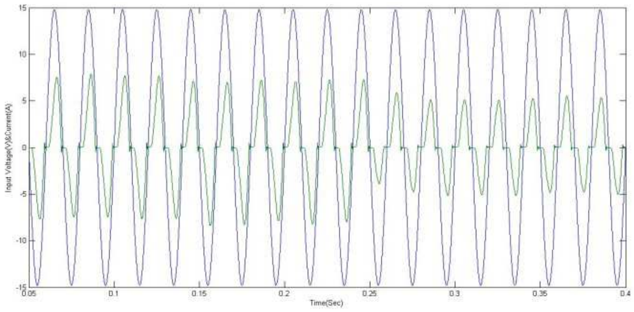

Fig.20.Input Voltage(V) & Current(A) With Step Change of load at 0.25sec for 230V(AC)/48V(DC)

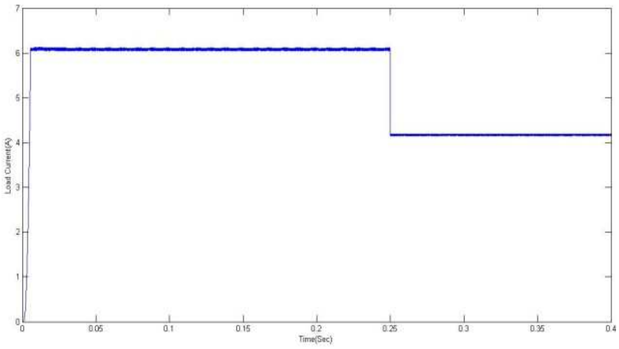

Fig.21.Output Current With Step Change of load from 300W to 200W at 0.25sec

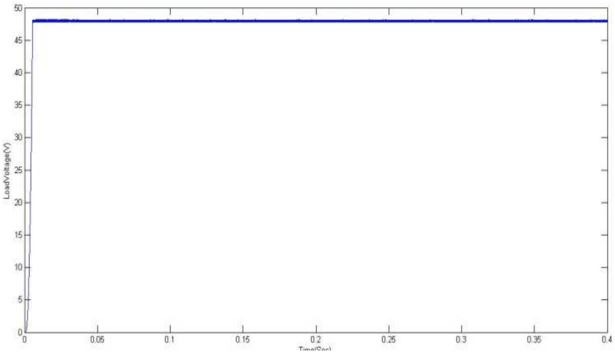

Fig. 22.Output Voltage(V) With Step Change of load from 300W to 200W at 0.25sec

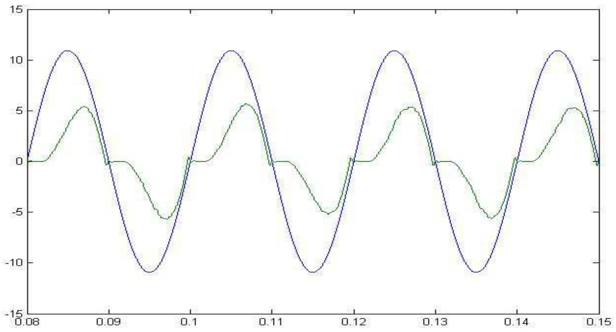

Fig. 23.Input Voltage(V) & Current(A) for 170V(AC)/48V(DC)

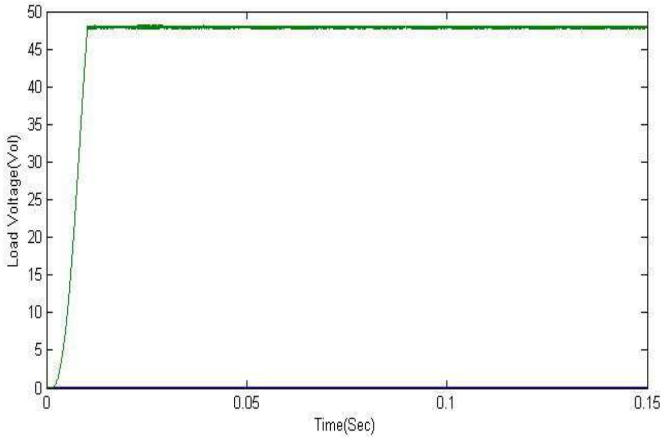

Fig24.Output Voltage (V) for 170V(AC)/48V(DC)

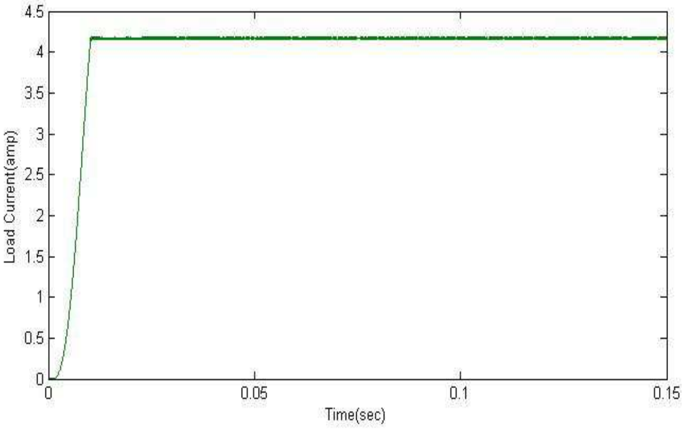

Fig.25.Output current(A) for 170V(AC)/48V(DC)

VI. CONCLUSION

Matlab/Simulink results for the LPCM Controlled IBFC for universal input (90-230V) range is shown in Table 1. Comparison of Matlab/Simulink results for the LPCM Controlled IBFC with Voltage mode controller technique is shown in Table 2.

TABLE 1.
MATLAB/SIMULINK RESULTS FOR LPCM CONTROLLED IBFC FOR UNIVERSAL INPUT (90-230V)

Input AC Voltage(Vol)	**Power factor**	**Settling Time(Sec)**	**% Peak overshoot**
90V	0.88	13msec	No peak overshoot
170V	0.9	10msec	No peak overshoot
200V	0.92	5.2msec	No peak overshoot
230V	0.96	3.5msec	No peak overshoot

TABLE 2.
COMPARISON TABLE BETWEEN VOLTAGE MODE CONTROLLER AND LPCM CONTROLLER FOR 230V(AC)/48V(DC)

Parameter	**Without step change in VMC**	**With step change in VMC**	**Without step change in load LPCM**	**With Step Change in load LPCM**
Power Factor	0.92	0.93	0.96	0.96
Output voltage	48	48	48	48
Ripple in output voltage	1V	1.2V	0.3	0.4V
Settling time	5msec	6msec	3.5msec	3.7msec
%Peak overshoot	12.3%	14.72%	No Peak overshoot	No Peak Overshoot

From Table 1. Proposed converter will work efficiently for universal range of input .From the comparison Table 2. LPCM controller is able to achieve faster transient response, zero peak over shoot, better rejection of disturbances than the voltage mode controller.

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