

Design and Simulation Analysis of Power Factor Correction Using Boost Converter with IC UC3854

Santhosh Kumar R¹, Shreeshayana R²

Assistant Professor, Department of EEE, ATMECE, Mysuru, Karnataka, India¹

Assistant Professor, Department of EEE, ATMECE, Mysuru, Karnataka, India²

ABSTRACT: In recent scenario many appliances requires DC power supply. Hence to obtain the DC power from input ac supply, Power Electronics circuits like Rectifiers which is a non-linear load has to be used. The current drawn by these non-linear load will be phase will not follow the supply voltage (i.e non sinusoidal). This results in a High Total Harmonic Distortion (THD) and Low Power Factor (PF). Hence the Power factor has to be improved and line current harmonics has to be reduced. The most commonly used topology for improving the PF in supply side is Active PFC using boost converter. The design and simulation of boost converter with Average Current Mode control in continuous conduction mode is presented in this paper. The output waveforms of the Power Factor Correction circuit is compared using two simulation tools.

KEYWORDS : Average Current Mode Control, Active Power Factor Correction, Continuous Conduction Mode.

I. INTRODUCTION

The demand on solid state AC-DC power converters increases from time to time. They are employed in several application areas such as uninterruptable power supplies (UPSs), back up energy storage systems, hybrid electric vehicle chargers, power supply for telecom loads and adjustable speed drives (ASDs). However, the power converters draw pulsating input current from the utility grids which results in poor power factor. Meanwhile, the converters pollute the AC mains by injecting significant amount of harmonic current from the switching devices due to high switching frequency. Improving the poor power quality becomes a great challenge for power supplying utilities as well as power converter manufacturers. The PFC circuit can reduce a significant amount of current harmonics. Low electromagnetic interference (EMI) can be achieved by employing boost type PFC converter as compared to other types of active PFC converters in continuous conduction mode (CCM). Moreover, most of the bridgeless topologies implemented so far are boost type configuration (also referred as dual-boost PFC rectifiers) because of its low cost and its high performance in terms of efficiency, power factor and simplicity. Hence, this project targets to design power factor correction using boost converter [1].

The input ac supply is converted into dc using diode bridge rectifier with a large output filter capacitor is cheap and robust, but it demands a harmonic rich ac line current. The rectification circuit as shown in Fig. 1, where the input power factor is poor. The low power factor and high pulsating current from the AC mains are the main disadvantages of the diode rectifier. Rectification is used in SMPS. So, power factor of SMPS is very poor.

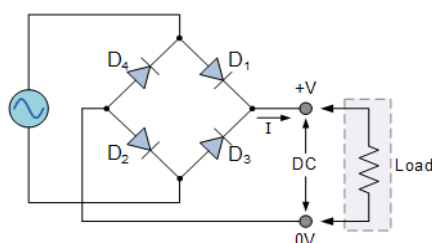


Fig.2. Rectifier Circuit

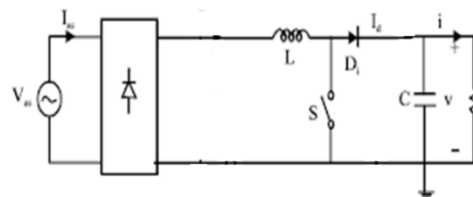


Fig. 2. Rectifier Circuit with Boost Converter

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To overcome these type of power quality problems different power electronics converter topologies are employed, out of which the boost converter topology has been extensively used as shown in Fig. 2. The boost converter can be operated in two modes, namely continuous conduction mode (CCM) and Discontinuous conduction mode (DCM). Any on method can be used for the PFC. In this paper we present the CCM of operation.

In the boost converter the capacitor maintains a voltage of approximately the peak voltage of the input sine wave until the next peak comes along to recharge it. In this case, current is drawn from the input only at the peaks of the input waveform, and this pulse of current must contain enough energy to sustain the load until the next peak. It does this by dumping a large charge into the capacitor during a short time, after which the capacitor slowly discharges the energy into the load until the cycle repeats. The input current waveform that doesn't follow the input voltage waveform is as shown in Fig. 3.

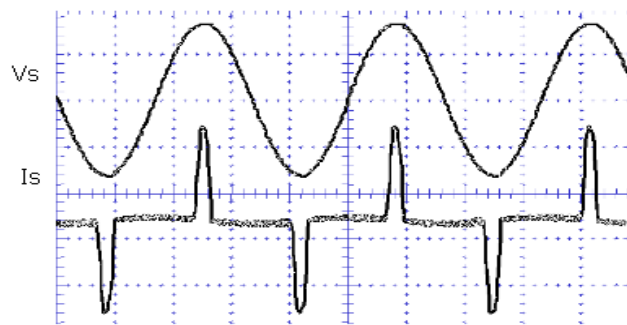


Fig. 3. Supply Current and Voltage Waveform without PFC

There are two control objectives for the boost converter in a PFC, namely Attaining a nearly constant output voltage and Keeping the average value of the input current nearly proportional to the input voltage thus obtaining a close to unity power factor. Fig.4 shows Power Factor Correction Using Boost Converter and Fig.5 shows the waveform of the supply current and voltage after the PFC circuit.

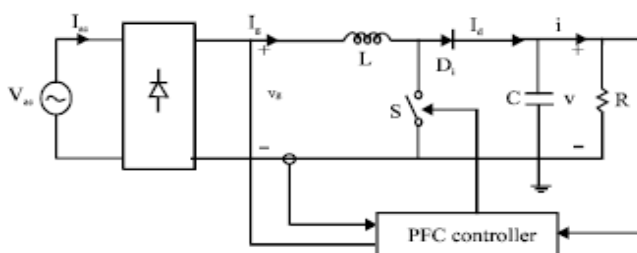


Fig. 4. Power Factor Correction Using Boost Converter

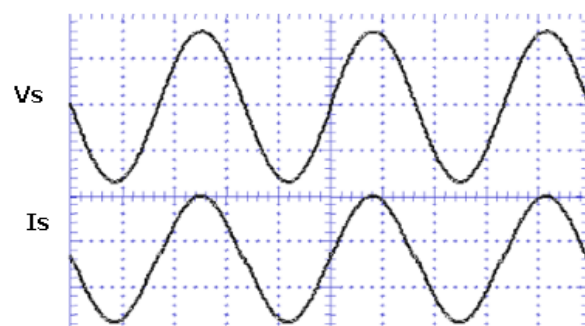


Fig. 5. Supply Current and Voltage Waveform with PFC

In the paper, three types of converters are considered and they were designed in two stages converter. The first stage deals with a rectification process that is AC to DC conversion together with PFC Boost topology while the second stage deals with DC to DC conversion as Boost converter topology was used. The preferable type of PFC is Active Power Factor Correction (APFC) since it provides more efficient power frequency. An active PFC uses a circuit to correct power factor and able to generate a theoretical power factor near to unity. Active Power Factor Correction also markedly diminishes total harmonics, automatically corrects AC input voltage, and capable for a wide range of input voltage.

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II. RELATED WORK

[2] Presents a bridgeless AC DC boost converter operating in CCM. The implementation of input current and output voltage controller is also discussed. Then a comparative analysis based on simulation results of bridgeless and bridge boost rectifier is presented. Bridgeless boost AC-DC converter has outperformed the conventional techniques due to lower conduction losses, lower THD of input current and improved input power factor.

[3] Introduces a single-stage active power factor correction (PFC) AC-DC converter which provides almost unity power factor and minimizes the THD to 7.4 %. For a constant DC output voltage a single phase diode bridge rectifier with a large output capacitor is considered in this paper. This standard topology has a shortcoming of introducing lower order harmonics and become cause of poor power factor, which needs to be improved.

[4] deals with an active input power factor correction with single phase bridge rectifier fed boost converter topology using hysteresis current control technique. The duty ratio is obtained by the comparison of a inductor current and a ramp carrier waveform which is associated with hysteresis controller in each switching period. Improvement in the supply current is illustrated in this work.

[5] In this paper, a novel discrete model has been proposed to simulate the controller IC UC3854. The main contributions are as followings: 1) The power stage of the Boost converter has been modelled by using the large signal approach and the loop gain of current program has been put forward; 2) The continues-time voltage control diagram has been investigated by employing equivalent power stage which contains the main circuit and current program; 3) Based on the continues-time model, a new discrete model of PFC has been given out and the operational principle has been introduced; 4) A 4kw prototype has been built up to verify the validity of the new model; Results of the simulation and the experiment show that the power factor is 96.7%.

[6] Presents an advanced Average Current-Mode Control (ACMC) technique for single phase AC-DC Boost Converter with Reactive Power Control. The leading phase admittance cancellation (LPAC) principle has been proposed to eliminate the current phase lead phenomenon. It results in reduction of the current control loop bandwidth requirement for a given line frequency.

III. AVERAGE CURRENT MODE CONTROL

The boost topology is a popular choice for a single-phase ac-dc pre-regulator with high power factor and low harmonic distortion of line ac current. The recently proposed ACMC has been widely used in PFC application.

Many companies are manufacturing the specific driver IC's for PFC switches. Some of them are, UC3854 -Texas Instruments, TDA 4862-Infineon Technologies, L6562 -ST Microelectronics. Here in the work we have used UC3854 IC from Texas Instruments. The integrated circuit UC3854 provides active power factor correction for power systems that would otherwise draw non-sinusoidal current from sinusoidal power lines. This IC implements all the control functions necessary to build a power supply capable of optimally using available power-line current while minimizing line-current distortion. In order to achieve this, the IC UC3854 contains voltage amplifier, analog multiplier/divider, current amplifier, and fixed-frequency pulse width modulator. In addition to this, it contains a power MOSFET compatible gate driver, voltage reference, line anticipator, load-enable comparator, low-supply detector, and over current comparator. UC3854 uses average current-mode control to accomplish fixed frequency current control with stability and low distortion. Unlike peak current-mode, average current control accurately maintains sinusoidal line current without slope compensation and with minimal response to noise transients. The inbuilt high reference voltage and high oscillator amplitude minimize noise sensitivity while fast pulse width modulator elements permit chopping frequencies above 200 kHz. Thus UC3854 can be used in single and three phase systems with line voltages that vary from 75 volt to 275 volt and line frequencies of 50Hz to 400Hz range. The wonderful feature of UC3854 is its low starting supply current that reduces the burden on the circuitry that supplies power to this device [7].

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IV. SYSTEM MODELLING

Power supply is the device that transfers electric power from a source to a load using electronic circuits. A typical application of power supplies is to convert utility's AC input power into regulated DC voltage required for electronic equipment. Depending on the mode of operation of power semiconductors PSU can be linear or switching (SMPS). The basic block diagram of SMPS is as shown in Fig. 6.

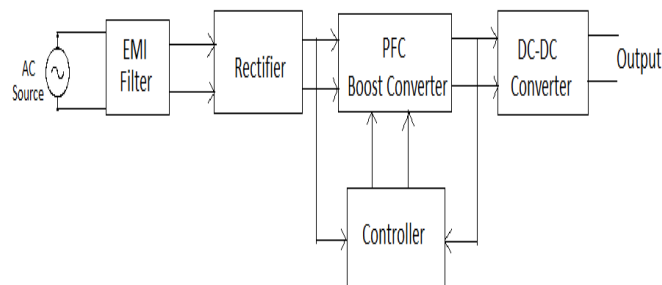


Fig. 6. Basic Block Diagram of SMPS

The SMPS mainly consist of EMI Filter section to attenuate the high frequency electromagnetic signals, Rectifier to convert AC to DC and then the reregulated Power Factor Correction circuit to improve the Power factor by reducing the THD levels. Finally it has DC-DC converter to get the desired output voltage.

The paper presents a design for the PFC circuit using Boost converter in closed loop mode to get the stable output voltage and to improve Power factor and hence efficiency. Then hardware model is done to verify the output of the designed circuit.

Another objective is to design a EMI filter which should pass only the line frequency signal and attenuate all other high frequency electromagnetic signals.

V. PFC CONTROL CIRCUIT DESIGN

The operating requirements for the active power factor corrector is Pout (max): 240W, Vin range: 80-270Vac, Line frequency range: 47-65Hz, Output voltage: 400Vdc, Select switching frequency: 100 KHz.

A. Passive Component Design

Inductor value is found using following steps

$$I_{pk} = \frac{\sqrt{2} * P_{in}}{V_{in(min)}} \quad \text{----- (Eqn.1)}$$

$$= 1.41 \times 240 / 80 = 4.23 \text{ A}$$

Ripple current

$$\Delta I = 0.2 * I_{pk}$$

$$\Delta I = 0.2 * 4.23 = 0.846 \text{ A}$$

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The duty factor at

$$D = \frac{V_0 - V_{in(\text{Peak})}}{V_0} \text{ (Eqn.2)}$$

$$D = (393 - 280) / 393$$

$$D = 0.287$$

$$L = (280 \times 0.287) / (100,000 \times 0.846) = 0.949 \text{mH}$$

$$\text{Let } L = 1.0 \text{ mH}$$

Output Capacitor value is found using following steps

$$C_0 = \frac{2 * P_{out} * \Delta t}{V_0^2 - V_1^2} \text{ (Eqn.3)}$$

Where Δt is the hold-up time in seconds and V_1 is the minimum output capacitor voltage.

$$= 2.3 \text{mF.}$$

$$\text{Let } C_0 = 1 \text{mF.}$$

Total peak current

$$I_{pk(\text{max})} = I_{pk} + \frac{\Delta I}{2} \text{ (Eqn.4)}$$

$$I_{pk(\text{max})} = 4.23 + \frac{0.846}{2} = 4.653 \text{A}$$

B. Control Circuit Design:

Sense Resistor value.

$$R_S = \frac{V_{rs}}{I_{pk(\text{max})}} \text{ (Eqn.5)}$$

$$R_S = \frac{1}{4.653} = 0.21 \Omega$$

Choose $R_S = 0.25 \Omega$

Peak sense voltage

$$V_{rs(\text{peak})} = I_{pk(\text{max})} * R_S \text{ (Eqn.6)}$$

$$= 4.653 * 0.25$$

$$V_{rs(\text{peak})} = 1.16 \text{V}$$

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Resistors in voltage divider

Assume peak current overload value

$$\begin{aligned}
 V_{rs(vold)} &= I_{pk(vold)} * R_S \quad \text{-----(Eqn.7)} \\
 &= 5.6 * 0.25 \\
 &= 1.4V \\
 R_{pk2} &= \frac{1.4 * 10000}{7.5} = 1.87K\Omega
 \end{aligned}$$

Maximum peak voltage

$$V_{peak} = \sqrt{2} * V_{in(max)} = 382V$$

$$R_{vac} = \frac{V_{peak(max)}}{600 * 10^{-6}} = 637k\Omega$$

Choosing $R_{VAC}=620K\Omega$

Bias resistor

$$R_{b1} = 0.25 * R_{vac} = 155K\Omega$$

Choosing $R_{b1}= 150k\Omega$

Sense resistor

$$R_{set} = \frac{3.75}{2 * I_{ac(min)}} = 10K\Omega$$

$$C_t = \frac{1.25}{R_{set} * f_s} = \frac{1.25}{10K * 100K} = 1.25nF$$

VI. CIRCUIT SIMULATION AND RESULTS

Circuit simulation is carried out using MATLAB Simulink and PSIM simulation softwares. The circuit was simulated without APFC circuit and with APFC circuit for rectifier. Circuit simulation of rectifier without Active PFC Circuit is shown in Fig. 7

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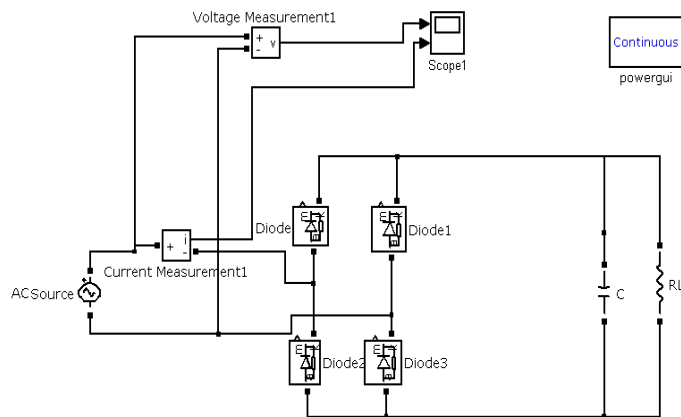


Fig. 7. Simulated Rectifier Circuit without PFC Circuit Using Matlab Circuit

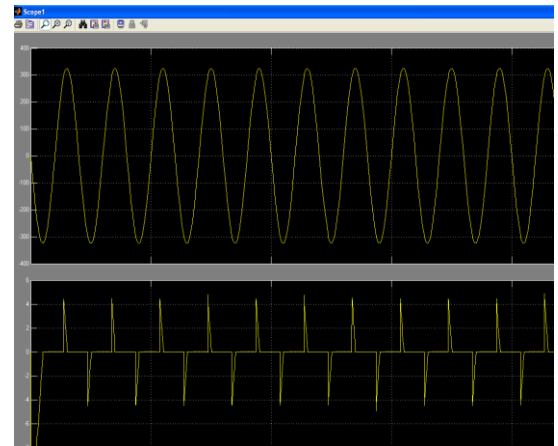


Fig. 8. Simulated Waveform of Rectifier Circuit Without PFC Using Matlab

From the simulated result shown in Fig 8, We can observe that the input current waveform shape is not same as that of input voltage and hence the power factor is going to reduce. The input power factor in this case will be around **0.4 to 0.6**.

Circuit simulation of Rectifier with Active PFC Circuit is shown in Fig. 9. From the Simulated Waveform Of Rectifier Circuit With PFC Circuit Using Matlab is shown in Fig.10 which shows improvement in power factor i.e **99%**.The current and voltage waveform can be seen in the Fig.10 and the test results are tabulated to verify the circuit designed.

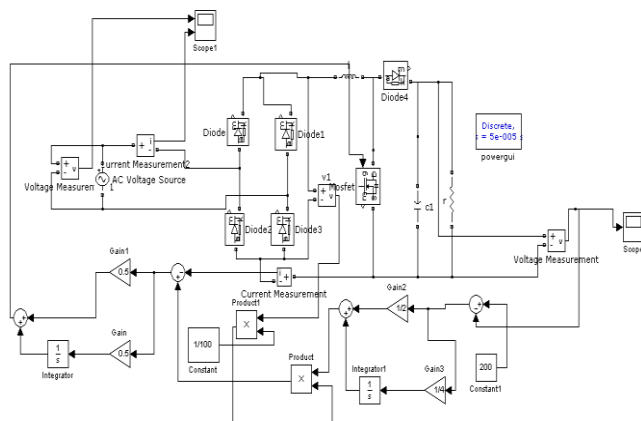


Fig. 9. Simulated Rectifier Circuit With PFC Circuit Using Matlab

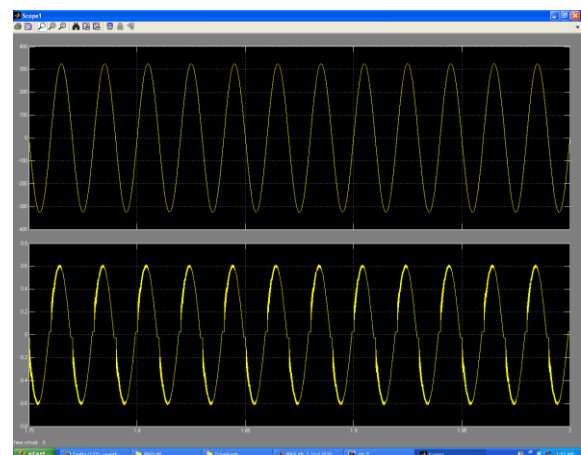


Fig. 10. Simulated Waveform of Rectifier Circuit with PFC Circuit Using Matlab

The result is tabulated in Table I below which summarises the parameters of simulated result with PFC in Matlab simulink software. The results obtained shows good power factor and indicates that the APFC circuits with ACMC can be used where distortion is produced in the line current in the electronic device applications.

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TABLE I: SIMULATED RESULT WITH PFC

Input Voltage(V)	Input Current(A)	Output Voltage(V)	Power factor
200	4	400	0.99

The Simulation of Rectifier circuit without PFC using PSIM simulation software is shown in Fig.11. The parameters designed and implemented in simulink, were also applied here. The results of the current and voltage waveforms have been discussed in the sections below.

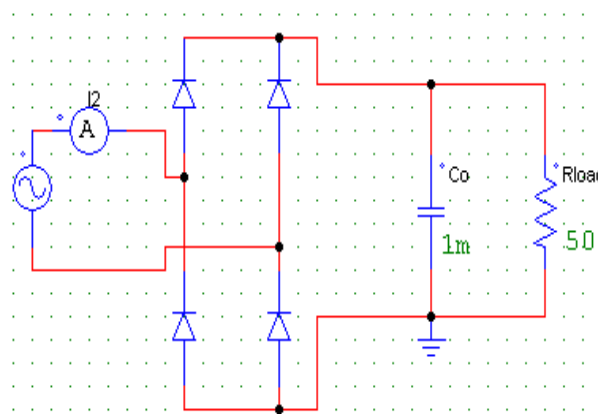


Fig .11 Simulated Rectifier Circuit without PFC Circuit Using PSIM

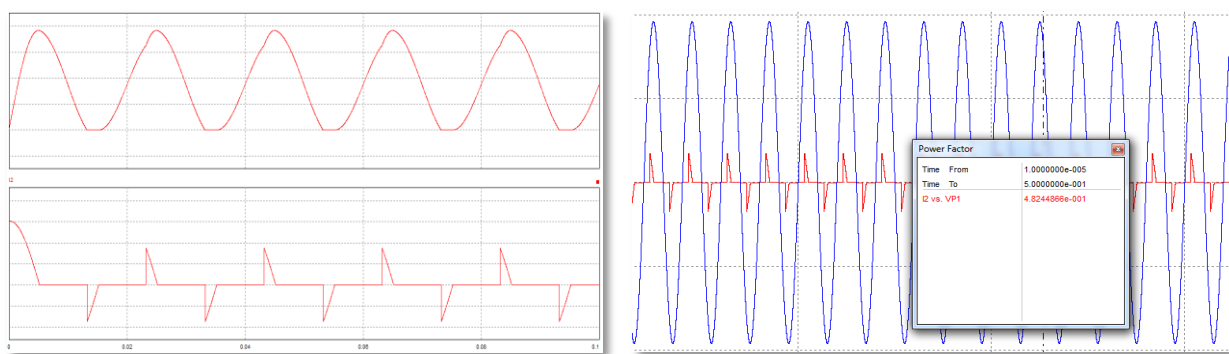


Fig .12. Output Current and Voltage Waveform without APFC

From the above simulated graph in Fig.12 we observe that the power factor is very low i.e 0.482 due to distortion in the input current waveform. To overcome the issue Simulation of Rectifier circuit with PFC was performed and is shown in Fig.13. By the addition of PFC IC UC3854 (Analog Technique) the results improved and can be visualized.

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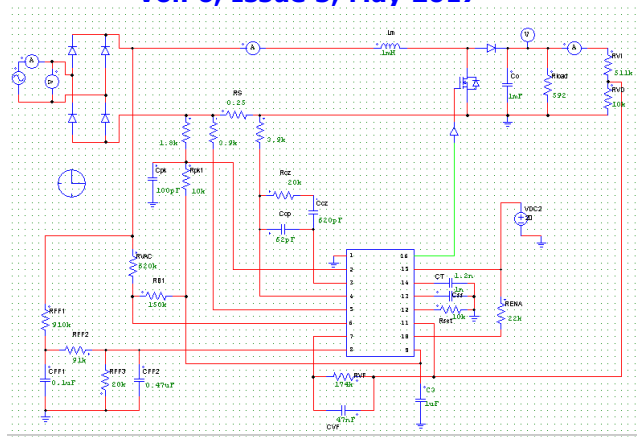


Fig .13. Circuit Diagram of PFC Using IC UC3854 (Analog Technique)

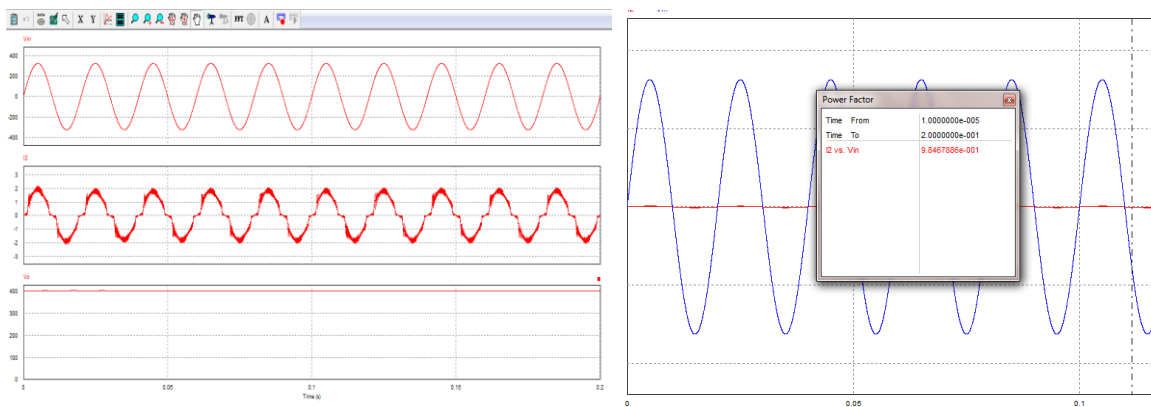


Fig .14. Simulation Result with PFC

From the Fig.14 we observe that the current waveform is in phase with the voltage waveform and the power factor is improved i.e to **98%**. The result is tabulated in Table 2 below which shows almost similar results obtained with simulink software. The analysis was performed to test the efficiency of the designed circuit.

TABLE2: Simulated result with PFC

Input Voltage(V)	Input Current(A)	Output Voltage(V)	Power factor
200	4	400	0.986

VII. CONCLUSION

The implementation of Average Current Mode Control (ACMC) with Boost converter using analog circuits (i.e. employing feedback using Voltage amplifier and Current amplifier) provided appreciable power factor. The power factor can be improved to about 98% by using this technique.

Also, on varying the input voltage from 80 – 270 Volts, the output voltage did not vary by a big margin; rather the range of Output voltage obtained was in the range of 390 – 400 Volts DC. Hence, the distortion produced in the line current in the electronic devices used for industrial and domestic applications due to harmonics and phase displacement

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caused by the rectified circuit can be nullified by Active Power Factor Correction circuits implementing Average current mode control with Boost converter using analog circuits.

REFERENCES

- [1] M. H. Rashid, Power Electronics Handbook, New York: Academic Press, 2001.
- [2] Mukhzan Mobeen Ali, Sardar Shazali Sikander, Usman Ali and Arbab Waleed, "An Active Power Factor Correction Technique for Bridgeless Boost AC-DC Converter", IEEE Explore, ISBN: 978-1-4673-8752-1, pp.129-134, 2016.
- [3] Pratap Ranjan Mohanty, Anup Kumar Panda and Dhiman Das, "An Active PFC Boost Converter Topology for Power Factor Correction", IEEE India Conference, ISBN: 978-1-4673-7399-9, pp.1-5, 2015.
- [4] S.Ramprasath, P.Ramesh Babu and A.Rekha, "Design and Simulation of Superior Quality Input Current Rectifier Based on Boost Topology" International Conference on Circuit, Power and Computing Technologies, ISBN: 978-1-4799-7075-9, pp.1-5, 2015.
- [5] R. Weiping Zhang, Fei Chen , Xusen Zhao and Yuanchao Liu, "A Discrete Modelling for Power Factor Correction Circuit", IEEE Explore, pp.160 – 163, 2010.
- [6] Parag Karekar, Ankit Deshpande, "Average Current-Mode Control with Leading Phase Admittance Cancellation Principle for Boost Converter", International Journal of Emerging Research in Management & Technology, Vol. 4, Issue 5, 2015
- [7] Datasheet for High Power Factor Pre regulator "IC UC 3854A".