INPUT POWER FACTOR CORRECTION USING BUCK CONVERTER IN SINGLE PHASE AC-DC CIRCUIT

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF TECHNOLOGY IN ELECTRICAL ENGINEERING

BY:

Jagannath Prasad Mishra (107EE066)

And

Rutwik Rath (107EE067)

Under the guidance of:

Prof. Anup Kumar Panda

DEPARTMENT OF ELECTRICAL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY

ROURKELA-769008

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National Institute of Technology, Rourkela

<u>CERTIFICATE</u>

This is to certify that thesis entitled "Input Power Factor Correction using Buck Converter in single phase AC-DC circuit", submitted by Jagannath Prasad Mishra (Roll No. 107EE066) and Rutwik Rath (Roll No. 107EE067), in partial fulfillment of the award of Bachelor of Technology in the Department of Electrical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Date: Prof. Anup Kumar Panda

Place: Rourkela   Dept. of Electrical Engineering

                                                                                            National Institute of Technology

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Jagannath Prasad Mishra

(Roll No. 107EE066)

Rutwik Rath

(Roll No. 107EE067)

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ABSTRACT

The devices generally used in industrial, commercial and residential applications need to undergo rectification for their proper functioning and operation. They are connected to the grid comprising of non-linear loads and thus have non-linear input characteristics, which results in production of non-sinusoidal line current. Also, current comprising of frequency components at multiples of line frequency is observed which lead to line harmonics. Due to the increasing demand of these devices, the line current harmonics pose a major problem by degrading the power factor of the system thus affecting the performance of the devices. Hence there is a need to reduce the line current harmonics so as to improve the power factor of the system. This has led to designing of Power Factor Correction circuits.

Power Factor Correction (PFC) involves two techniques, Active PFC and Passive PFC. In our project work we have designed an active power factor circuit using Buck Converter for improving the power factor. Average Current Mode Control method has been implemented with buck converter to observe the effect of the active power factor corrector on the power factor. The advantage of using Buck Converter in power factor correction circuits is that better line regulation is obtained with appreciable power factor.

CHAPTER 1

INTRODUCTION

1. INTRODUCTION

1.1 Objective of the Project Work & Introduction

The objective of our project work is the power factor correction of a system using Buck Converter.

Power Factor is an important performance parameter of a system. And improving power factor is very much essential for the better and economical performance of the system. If the power factor of a system at a given power requirement is poor, then large value of Volt – Amperes or large amount of current is required by the system which is drawn from the supply. Hence it is seen that various measures are taken to improve the power factor of a system.

[1] describes the use and design of a Boost pre-regulator for the Power Factor Correction. And [2] describes the design, use and analysis of Buck Converter for power Factor Correction. While [3] compares various DC-DC Converter topologies for Power Factor Correction. The basic purpose of a Power Factor Correction circuit is to make the line current follow the waveform of the line voltage so that the input to the power supply becomes purely resistive or behaves like a resistor and hence to improve the power factor.

Our project work makes the use of Buck Converter in the Power Factor Correction circuit so as to improve the power factor. Our project work starts with the description of Power Factor and other performance parameters associated with it in detail and then with the study and analysis of Buck Converter and with the advantages of using Buck Converter for Power Factor Correction.

We started our project work with the study and analysis of power factor of a system by doing simulations on P-SIM Software using full wave rectifier in the beginning. After studying and

analyzing the input current and voltage waveforms and the power factor of the system using Rectifier circuit, we introduced a Buck Converter in the circuit and then analyzed its effect in improving the power factor of the system.

1.2 <u>POWER FACTOR</u>

Power factor can be defined as:-

The ratio of active or real power to the apparent power.

$$\text{P.F} = \frac{Real\ Power}{Apparent\ Power}$$

$$= \frac{P}{Vrms\ X\ Irms}$$

Or $\text{P.F} = \frac{Watts}{V.A}$

Where, $\mathbf{V_{rms}}$ = Root Mean Square Voltage of Load

$\mathbf{I_{rms}}$= Root Mean Square Current of Load

If the load is purely resistive, then the real power will be same as $\mathbf{V_{rms}}^{\times} \mathbf{I_{rms}}$. Hence, the power factor will be 1.0.

And if the load is not purely resistive, the power factor will be below 1.0.

Power factor correction circuits are developed so that the power factor is improved which means it tries to make the input to a power supply behave like purely resistive or a resistor. This is done by trying to make the input current in response to the input voltage, so that a constant ratio is maintained between the voltage and current. This would ensure the input to be resistive in nature and thus, the power factor to be 1.0 or unity.

When the ratio between voltage and current is not constant i.e. the load is not purely resistive, or the input to the power supply is not resistive, then the input will contain phase displacement and harmonic distortion, both of which will severely affect and degrade the power factor [1].

1.3 PHASE DISPLACEMENT:

It is a measure of the reactance of the impedance of the input. The presence of reactance be it capacitance or inductance will cause displacement of the input current waveform with respect to the input voltage waveform.

Power factor can also be defined as the phase displacement of the voltage and current, which is expressed as the cosine of the phase angle between the voltage and current waveform.

$$P.F = Cos\Theta$$

The amount of displacement between the voltage and current gives us the idea about the degree to which the load is reactive.

So, if reactance contributes a small part to the impedance of the load, the phase displacement will be small. Also, filtering of alternating line current will produce phase displacement [1].

1.4 HARMONIC DISTORTION:

It is a measure of the non-linearity of the impedance of the input. If there is variation in the input impedance, which varies as a function of the input voltage, then there will be distortion of the input current and hence, this distortion will lead to poor power factor.

Distortion increases the RMS value of the current without increasing the total power being used or consumed or drawn. So, a non-linear load will have a poor power factor, since the value of the RMS current is high, but the total power delivered is small.

If the non-linearity is high or large, the harmonic distortion is large.

The active power factor correction units may have harmonic distortion effects from several sources like the feed-forward signals, the feedback loops, the output capacitor, inductor and the input rectifiers [1].

The effect of Total Harmonic Distortion on power factor can be seen to be inversely proportional in the graph shown below.
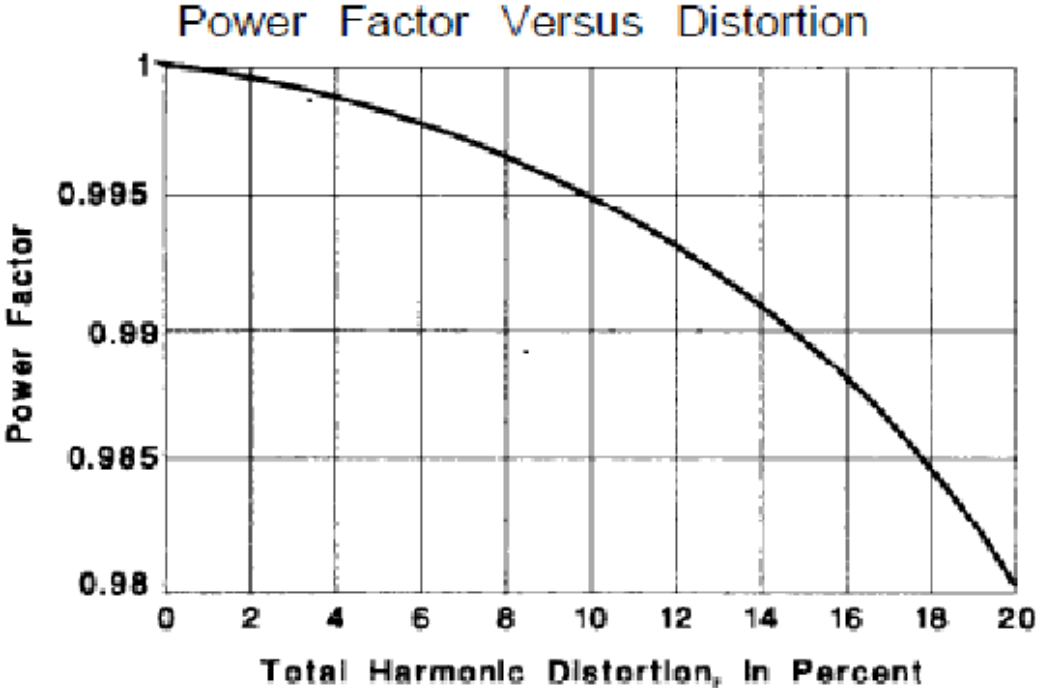
Fig 1.1: Graph showing Power Factor vs. Total Harmonic Distortion

The above graph was reproduced from [1].

Total Harmonic Distortion can be measured by Harmonic Factor which is defined as:-

Harmonic Factor (HF) = $\sqrt{\dfrac{I_s{}^2 - I_{s1}{}^2}{I_{s1}{}^2}}$

HF = $\sqrt{\left(\dfrac{I_s}{I_{s1}}\right)^2 - 1}$

Where, I_{s1}= Fundamental Component of the Input Current I_s.

And I_s= RMS value of input current.

1.5 <u>INPUT SUPPLY PERFORMANCE PARAMETERS:</u>

The AC supply current in a phase-controlled drive is non-sinusoidal, which will affect the performance of the drive. The performance can be measured by the help of the following terms given below:-

1) <u>Input Power Factor:</u>

   $\text{P.F} = \dfrac{Mean\ Input\ Power}{RMS\ Input\ Volt\ Amperes}$

   If the supply voltage is an undistorted sinusoidal, then only the fundamental component of the input current, would contribute to the mean input power.

   Therefore, $\text{P.F} = \dfrac{VI_1 cos\phi_1}{VI}$

   Where, V = RMS value of supply phase voltage

         I = RMS value of supply phase current

         I_1= RMS value of fundamental component of the supply current

       & ϕ_1= Angle between the supply voltage and fundamental component of the supply current.

Input power factor is very important as it decides how much volt-amperes is required by the system. So, for a certain power demand of a system, if the power factor is very poor, then more or large amount of volt-amperes and thus, large value of current are drawn from the supply.

2) Input Displacement Factor:

It is defined as $\cos\phi_1$ or DF=$\cos\phi_1$.

Where, ϕ_1= Input displacement angle

If, for a certain power demand, if displacement factor is low, then large value of fundamental current is drawn from the supply.

3) Harmonic Factor:

Since, the input current is non-sinusoidal in nature, it contains currents of harmonic frequencies. It is defined as:-

Harmonic Factor (HF) = $\sqrt{\dfrac{I^2-I_1^2}{I_1^2}}$

$$= \dfrac{\sqrt{I^2-I_1^2}}{I_1}$$

$$= \dfrac{\sqrt{\sum_2^\infty In^2}}{I_1}$$

HF = $\dfrac{In}{I_1}$

Where, In = RMS value of nth harmonic current

I_1= RMS value of the fundamental component of the supply current.

The Harmonic Factor (HF) gives us idea about the harmonic contents in the input supply current and measures the Total Harmonic Distortion.

1.6 <u>Fourier Analysis of Input Supply Current:</u>

The input supply current (i) can be expressed in Fourier Series as follows:-

$$i = I_0 + \sum_{n=1}^{\infty}(a_n \cos n\omega t + b_n \sin n\omega t)$$

$$= I_0 + \sum_{n=1}^{\infty}\left(\sqrt{2}I_n \sin(n\omega t + \emptyset n)\right)$$

I_0 is the DC component.

The Fourier Coefficients a_n and b_n are:

$$I_0 = \frac{1}{T}\int_0^T i\, dt$$

$$a_n = \frac{2}{T}\int_0^T i \cos n\omega t\, dt$$

$$b_n = \frac{2}{T}\int_0^T i \sin n\omega t\, dt$$

$$I_n = \sqrt{\frac{a_n{}^2 - b_n{}^2}{2}}$$

And $\emptyset_n = \tan^{-1}\left(\frac{a_n}{b_n}\right)$

For Power Factor Correction, we are using Buck-Converter.

CHAPTER 2

BUCK CONVERTER

2. BUCK CONVERTER

2.1 BUCK CONVERTER:

It is a converter in which the output voltage is less than the input voltage. It is like a step-down converter. In figure Fig 2.1, $V_a < V_s$.

The circuit diagram of Buck Converter using a power BJT is as follows:-
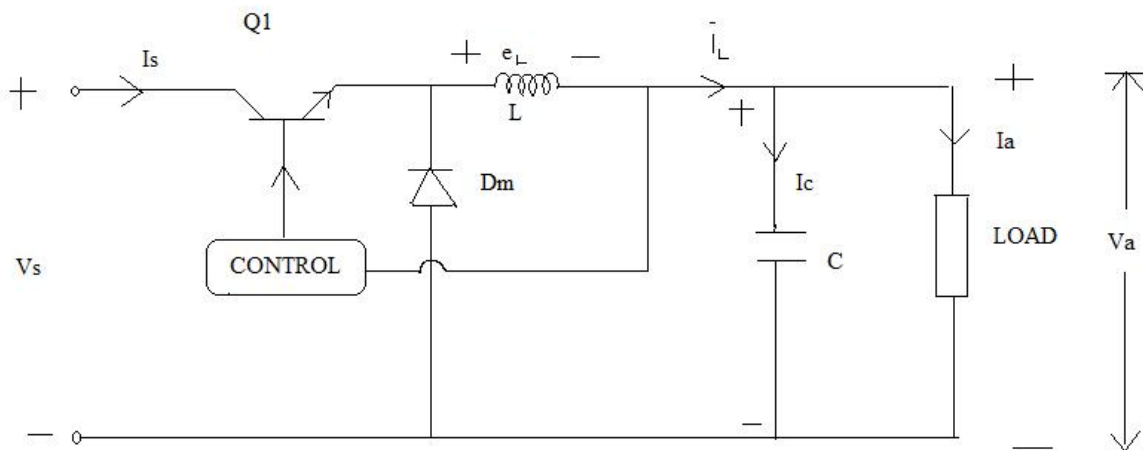
Fig 2.1: Circuit Diagram of Buck Converter

The operation of Buck Converter can be described in two modes.

2.2 Modes of Operation of Buck Converter

Mode-1: It begins when transistor Q_1 is switched ON at t=0.

The input current rises, flows through filter inductor L, filter capacitor C and load resistor R.

The circuit diagram showing operation of Buck Converter in Mode-1 is shown below.

Fig 2.2: Mode 1 operation of Buck Converter

Mode-2: It begins when transistor Q_1 is switched OFF at $t=t_1$.

The freewheeling diode D_m conducts because of the energy stored in the inductor and the current flows through L, C, load and diode D_m.

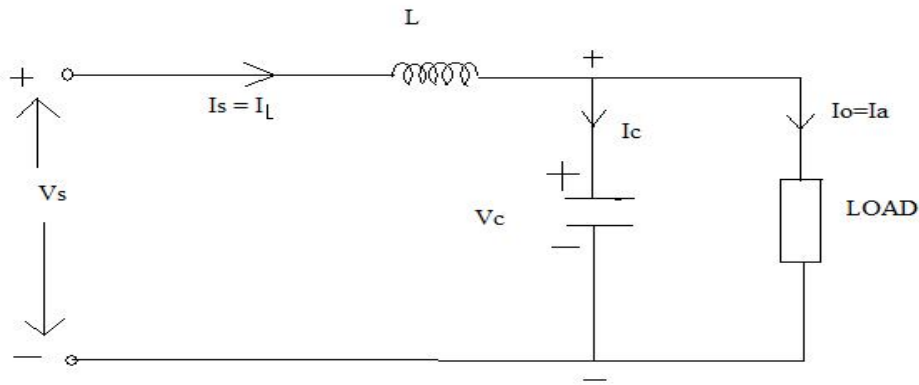The circuit diagram showing operation of Buck Converter in Mode 2 is shown below.
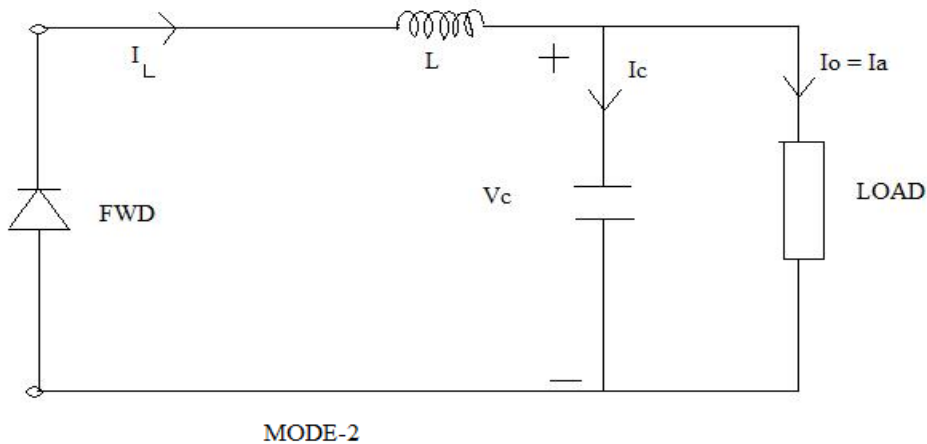
MODE-2

Fig 2.3: Mode 2 operation of Buck Converter

2.3 <u>ANALYSIS:</u>

Voltage across inductor $\mathbf{L} = \mathbf{e_l} = \mathbf{L}\frac{di}{dt}$

Suppose the inductor current rises linearly from I_1 to I_2 in time t_1.

1. $\mathbf{Vs} - \mathbf{V_a} = \mathbf{L}\frac{I_2 - I_1}{t_1} = \mathbf{L}\frac{\Delta I}{t_1}$

2. $\boldsymbol{t_1} = \frac{\Delta IL}{V_s - V_a}$ (1)

And if the inductor current falls from I_2 to I_1 in time t_2, we have

3. $\mathbf{0} - \mathbf{V_a} = -\mathbf{L}\frac{\Delta I}{t_2}$

4. $\mathbf{t_2} = \frac{\Delta IL}{V_a}$ (2)

From (1) and (2), $\Delta I = \frac{V_s - V_a}{L}t_1 = \frac{V_a t_2}{L}$

Let, $t_1 = kT$ & $t_2 = (1-k)T$

5. $\mathbf{V_a} = \frac{V_s t_1}{T} = \mathbf{kV_s}$ = Average Output Voltage

Assuming a lossless circuit,

$\mathbf{V_s I_s} = \mathbf{V_a I_a} = \mathbf{kV_s I_a}$

And $\mathbf{I_s} = \mathbf{kI_a}$ = Average Input Current

Therefore, Switching Period $\mathbf{T} = \frac{1}{f} = \boldsymbol{t_1} + \boldsymbol{t_2} = \frac{\Delta IL}{V_s - V_a} + \frac{\Delta IL}{V_a}$

$$= \frac{\Delta ILV_s}{V_a(V_s - V_a)}$$

6. The peak to peak ripple current is:-

$$\Delta I = \frac{V_a(V_s - V_a)}{fLV_s}$$ (3)

Now from figure, $i_L = i_c + i_a$

Assuming the load ripple current $\Delta i_\circ$ to be very small and negligible, $\Delta i_L = \Delta i_C$.

The average capacitor current flows for $\frac{t_1}{2} + \frac{t_2}{2} = \frac{T}{2}$

7. $I_C = \frac{\Delta I}{4}$

$$v_C \ (Capacitor \ Voltage) = \frac{1}{C} \int i_C dt + v_C|t = 0$$

Peak to peak ripple voltage of the capacitor is:-

$$\Delta v_C = v_C - v_C|t = 0 = \frac{1}{C} \int_0^{T/2} \frac{\Delta I}{4} dt = \frac{\Delta IT}{8C}$$

Or $\Delta v_C = \frac{\Delta I}{8fC}$

Using ΔI from (3), we have:-

$$\Delta v_C = \frac{V_a(V_s - V_a)}{8LCf^2V_s}$$

There are some conditions for the inductor current and capacitor voltage to be continuous.

Let I_L = Average inductor current

8. Inductor Ripple Current(ΔI) = $2I_L$

9. Now, $V_a = V_s \frac{t_1}{T} = kV_s$

$$\&\Delta I = \frac{V_s k(1-k)}{fL}$$

10. $\Delta I = 2I_L = \frac{V_s k(1-k)}{fL} = 2I_a$

11. The critical value for inductor (L_c) is:-

$$L_C = L = \frac{(1-k)R}{2f} \tag{4}$$

Let, V_c= Average Capacitor Voltage

ΔV_C = Capacitor Ripple Voltage = $2V_a$

$$V_a = \frac{V_s t_1}{T} = kV_s$$

$$\& \Delta V_C = \frac{V_s k(1-k)}{8LCf^2} = 2V_a = 2kV_s$$

12. The critical value of the capacitor C_c is:-

13. $C_c = C = \frac{1-k}{16Lf^2}$ (5)   [4]

2.4 WAVEFORMS

The waveforms of switching state, current and voltage during continuous conduction mode (CCM) operation of Buck Converter are given below. In figure Fig 3.4, shown below,

T_{on}= On period of transistor,

T_{off} = Off period of transistor,

V_i = Input Voltage,

V_o = Output Voltage,

V_L = Voltage across inductor L,

V_D = Voltage across diode Dm,

I_L = Current flowing through the inductor,

I_{max} = Maximum value of I_L,

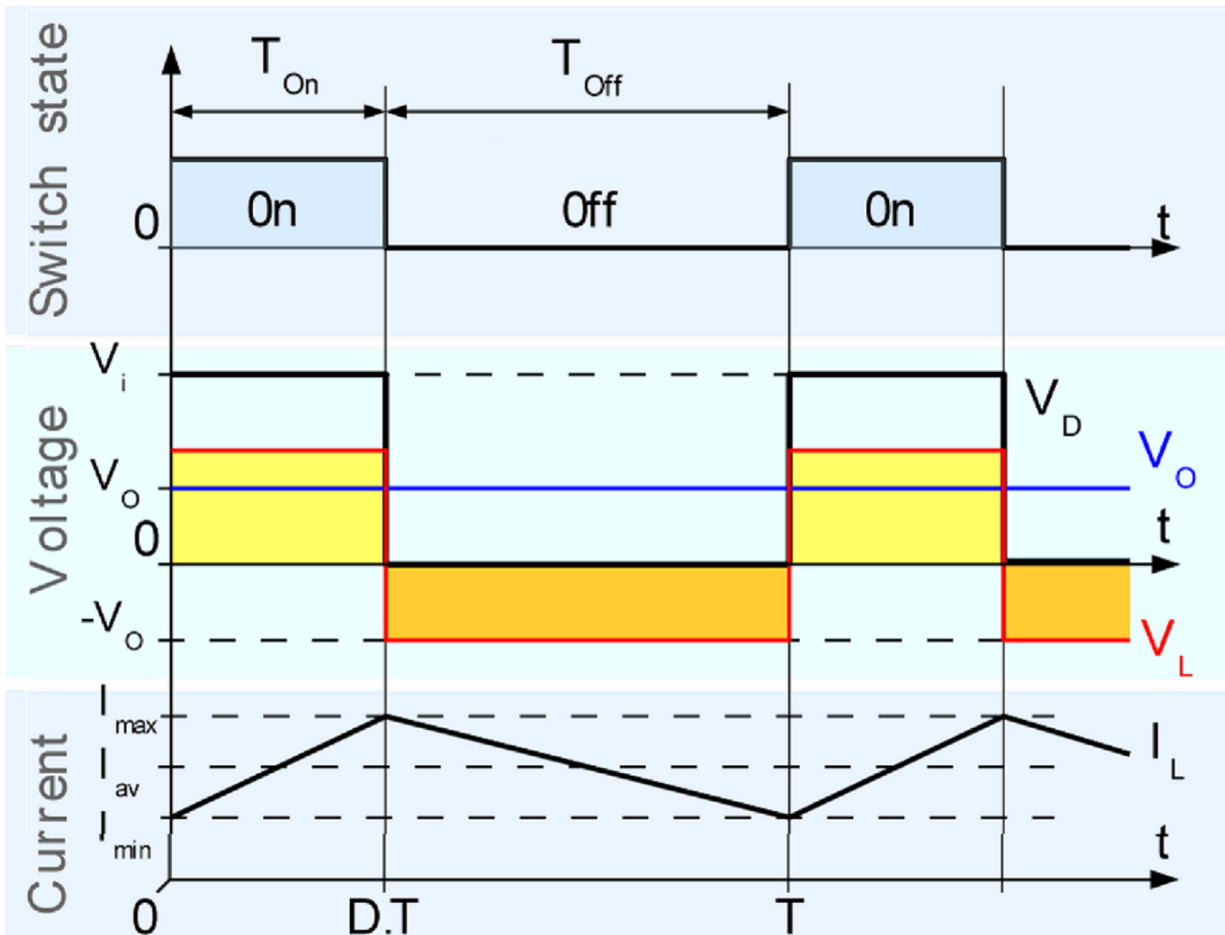I_{min} = Minimum value of I_L,

D = Duty cycle=$\frac{V_o}{V_i}$.

Fig 2.4: Waveforms obtained in Continuous Conduction Mode of Buck Converter

The above graph was reproduced from [10].

During T_{on}, $V_L = V_i - V_o$. The diode Dm becomes reverse biased and current through inductor rises in linear manner.

During T_{off}, $V_L = -V_o$. The diode Dm becomes forward biased and current through inductor decreases.

2.5 ADVANTAGES OF BUCK CONVERTER FOR POWER FACTOR CORRECTION

1) It requires only one transistor and is simple.

2) It has high efficiency, more than 90%.

3) The inductor limits the rate of change of load current.

But, the input current is discontinuous and a smoothing input filter is required.

Buck converter provides one polarity of output voltage and unidirectional output current.

In systems such as universal line AC-DC converters [2], it is very difficult to improve power factor where high efficiency is required throughout the entire line. A Power Factor Correction circuit using Boost Converter possesses 1% to 3% lower efficiency at 100 Volts than that at 230 Volts. This is due to increased input current that produces higher losses in semiconductors and input filters. Also the high output voltage of Boost Converter in 380-400 Volts range has a detrimental effect on its switching losses and on the size and efficiency of the isolation transformer.

The above drawbacks of Boost Converter in Power Factor Correction circuit can be overcome by using Buck Converter with output voltage in 135 Volts range which has higher efficiency throughout the line. Also the lower input voltage to the DC-DC output stage can now be operated with lower voltage rated semiconductors, optimized loss and size of isolation transformer and better performance.

CHAPTER 3

POWER FACTOR CORRECTION

3. POWER FACTOR CORRECTION

3.1 Power Factor Correction (PFC)

Power factor correction is the method of improving the power factor of a system by using suitable devices. The objective of power factor correction circuits is to make the input to a power supply behave like purely resistive or a resistor. When the ratio between the voltage and current is a constant, then the input will be resistive hence the power factor will be 1.0. When the ratio between voltage and current is other than one due to the presence of non-linear loads, the input will contain phase displacement, harmonic distortion and thus, the power factor gets degraded [5-7].

3.2 Need of PFC

The rise in the industrial, commercial and residential applications of electronic equipments has resulted in a huge variety of electronic devices requiring mains supply. These devices have rectification circuits, which is the prominent reason of harmonic distortion. These devices convert AC to DC power supply which causes current pulses to be drawn from the ac network during each half cycle of the supply waveform. Even if a single device for example, a television may not draw a lot of reactive power nor it can generate enough harmonics to affect the supply system significantly, but within a particular phase connection, there may exist several such devices connected to the same supply phase resulting in production of a large amount of reactive power flow and harmonics in line current [5-7].

With improvement in the field of semiconductors, the size and weight of control circuits have drastically reduced. This has also affected their performance and thus power electronic converters have become increasingly popular in industrial, commercial and residential applications. However this mismatch between power supplied and power used cannot be detected by any kind of meter meant for charging the domestic consumers, and hence, results in direct loss of revenues [5-7].

Moreover, since different streets are supplied with different phases, a 3-phase unbalanced condition may also arise within a housing scheme. The unbalance current flows in the neutral line of a star connected network causing undesirable heating and burning of the conductor [5-7].

This pulsating current contains harmonics which results in additional losses and dielectric stresses in capacitors and cables, increasing currents in windings of rotating machinery (e.g., induction motors) and transformers and noise emissions in many equipments. The rectifier used in the AC input side is the prime source of this problem. Thus, in order to decrease the effect of this distortion, power factor correction circuits are added to the supply input side of equipments used in industries and domestic applications to increase the efficiency of power usage [5-7].

3.3 Types of Power Factor Correction (PFC)

Power Factor Correction can be classified as two types:

1. Passive Power Factor Correction

2. Active Power Factor Correction

3.3.1 Passive Power Factor Correction

In Passive PFC, in addition to the diode bridge rectifier, passive elements are introduced to improve the nature of the line current. By using this, power factor can be increased to a value of 0.7 to 0.8 approximately. As the voltage level of power supply increases, the sizes of PFC components increase. The idea of passive PFC is to filter out the harmonic currents by use of a low pass filter and only allow the 50 Hz power frequency wave to increase the power factor [5], [7].

3.3.2 Advantages of Passive PFC :

- It has a simple structure.

- It is reliable and rugged.

- The cost is very low because only a filter is required.

- The high frequency switching losses are absent and it is not sensitive to noises and surges.

- The equipments used in this circuit don't generate high frequency EMI [5], [7].

3.3.3 Disadvantages of Passive PFC :

- For achieving better power factor the size of the filter increases.

- Due to the time lag associated with the passive elements it has a poor dynamic response.

- The voltage cannot be regulated and the efficiency is low.

- Due to presence of inductors and capacitors interaction may take place between the passive elements and the system resonance may occur at different frequencies.

- Although by filtering the harmonics can be filtered out, the fundamental component may get phase shifted thus reducing the power factor

- The shape of input current is dependent upon what kind of load is connected [5],[7].

3.3.4 Active Power Factor Correction

An active PFC is a power electronic device designed to control the amount of power drawn by a load and obtains a power factor as close as possible to unity. Commonly any active PFC design functions by controlling the input current in order to make the current waveform follow the supply voltage waveform closely (i.e. a sine wave). A combination of the reactive elements and some active switches increase the effectiveness of the line current shaping and to obtain controllable output voltage [5], [7], [8].

The switching frequency differentiates the active PFC solutions into two classes.

➢ Low frequency active PFC:

Switching takes place at low-order harmonics of the line-frequency and it is synchronized with the line voltage.

➢ High frequency active PFC:

The switching frequency is much higher than the line frequency.

The power factor value obtained through Active PFC technique can be more than 0.9. With a suitable design even a power factor of 0.99 can be achieved easily. Active PFC power supply can detect the input voltage automatically, supports 110V to 240V alternative current, its size and weight is smaller than passive PFC power supply [5], [7], [8].

3.3.5 <u>Advantages of Active PFC</u> :

- The weight of active PFC system is very less.

- The size is also smaller and a power factor value of over 0.95 can be obtained through this method.

- It reduces the harmonics present in the system.

- Automatic correction of the AC input voltage can be obtained.

- It is capable of operating in a full range of voltage [5], [7], [8].

3.3.6 <u>Disadvantages of Active PFC</u> :

- The layout design is somewhat more complex than passive PFC.

- It is very expensive since it needs PFC control IC, high voltage MOSFET, high voltage ultra-fast choke and other circuits [5], [7], [8].

CHAPTER 4

CURRENT MODE CONTROL

4. CURRENT MODE CONTROL

In this method, the buck regulator input current is forced or programmed to be proportional to the input voltage waveform for power factor correction. Feedback is necessary to control the input current.

4.1 Types of Current Mode Control

There are two types of current mode control:

- ➤ Peak Current Mode Control(PCMC), and

- ➤ Average Current Mode Control (ACMC).

Implementing peak current mode control in a PFC circuit has the following disadvantages:-

1) It has a low gain.

2) It has a wide band-width which makes it unsuitable for a high performance PFC since there is a significant error between the programming signal and current which leads to distortion and a poor power factor [1], [7], [11].

Hence, the control circuit for the buck converter is implemented using Average Current Mode Control (ACMC) method.

4.2 AVERAGE CURRENT MODE CONTROL (ACMC)

It is based on a simple concept where an amplifier is used in the feedback loop around the buck power stage so that the input current follows the current programming signal with minimum error.

The power circuit of a buck power factor corrector is the same as that of a dc to dc buck converter. There is a single phase diode bridge to rectify the AC input voltage. The output of the

buck regulator is a constant voltage but the input current is programmed by the input voltage .The method involves the control of both the input current and the output voltage [1], [7], [11].

The salient features of ACMC are:

- The current loop is programmed by the rectified line voltage so that the input to the converter will be approximately resistive.

- The average amplitude of the current programming signal is changed to control the output voltage.

- An analog multiplier is used which multiplies the rectified line voltage with the output of the voltage error amplifier to give the current programming signal(Imo) which has the shape of the input voltage and an average amplitude to control the output voltage.

- The multiplier input from the rectified line voltage is shown as a current signal rather than a voltage one.

- A squarer, divider and a multiplier is used in the voltage loop.

- The output of the voltage error amplifier (Vvea) is divided by the square of the average input voltage before being multiplied by the input voltage signal. This is done to keep the gain of the voltage loop constant without which it would vary as the square of the average input voltage (Vff).

- The voltage loop bandwidth is kept less than the input line frequency because if it is large then it would modulate the input current to keep the output voltage constant thereby resulting in large distortion of input current.

- At the same time the voltage loop bandwidth should be large enough for fast output voltage transient response.

- Squarer and divider are used to keep the loop gain constant so that the loop bandwidth can be made as close as possible to the line frequency to minimize the transient response of the output voltage.

- The circuits which keep the loop gain constant make Vvea a power control which controls the power delivered to the load [1], [7], [11].

The basic control circuit arrangement necessary for an active power factor corrector is shown below:
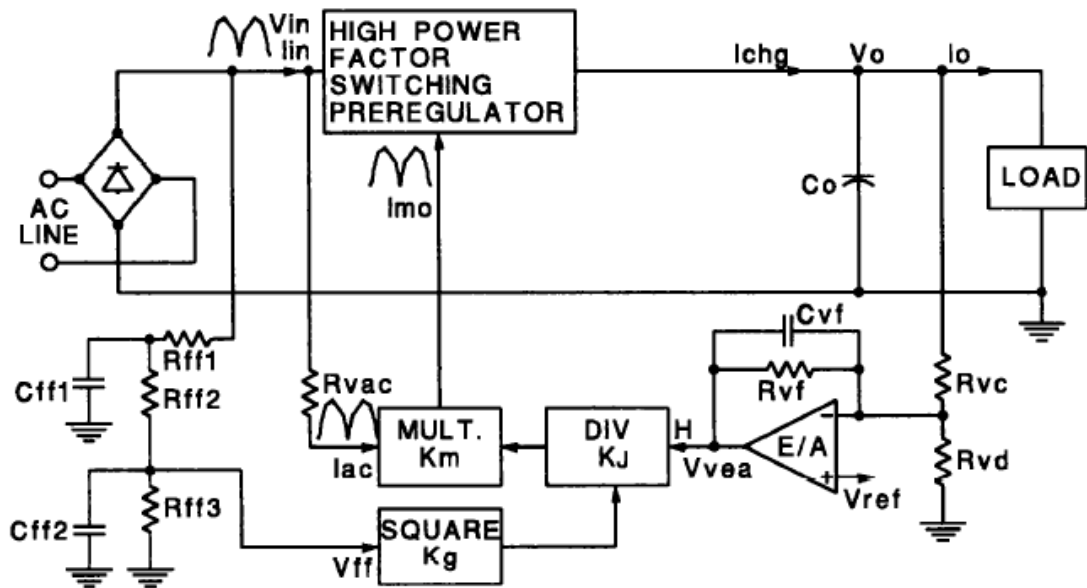

Fig 4.1: Active Power Factor Correction Circuit

The above picture was reproduced from [1].

The control circuit introduces both distortion and displacement into the input current waveform. The sources of error mainly include the input diode bridge, the multiplier circuit and ripple voltage, both on the output and on the feed forward voltage.

There are two modulation processes in an active power factor corrector:

- The input diode bridge

- The multiplier, divider and squarer circuit.

Cross products, harmonics or sidebands are generated between the two inputs during each modulation process. The two modulators interact and one serves as a demodulator for the other so that the result is quite simple and thus, all of the ripple voltages are at the second harmonic of the line frequency.

The Vff should be as low as possible to minimize the distortion in input current [1].

4.3 Advantages of ACMC:

- Better line regulation is achieved using ACMC.

- It operates with a constant switching frequency.

- Here no compensation ramp is required.

- Since the current is filtered the control is less sensitive to commutation noises unlike peak current mode control.

- The duty cycle is close to one near the zero crossing of the line voltage hence, better input current waveforms are obtained than for the peak current control [1], [7], [11].

4.4 Disadvantages of ACMC :

- The inductor current has to be sensed.

- Here a current error amplifier is required for which a compensation network has to be designed for different converter operating points [1], [7], [11].

CHAPTER 5

SAMPLE DESIGN

5. SAMPLE DESIGN

For designing a sample circuit for power factor correction, a power factor corrector of output rated at 90W is taken. Even though the power stage design varies, the design process is the same for all ratings.

5.1 Specifications of Active Power Factor Corrector:

   Pout (max): 90W

   Input Voltage (V_{in}): 220Vac

   Line frequency: 50Hz

   Output voltage (V_{out}): 135Vdc

 5.2   Selection of Switching Frequency:

   The switching frequency should be large enough to minimize the size of the power circuit and reduce distortion. Moreover it should be less for higher efficiency. Hence, a switching frequency of 100 KHz is chosen.

5.3 Inductor Selection:

   The maximum peak current (I_{pk}) which flows through the inductor when the input voltage value is minimum, is first obtained.

   At maximum peak line current I_{pk}, Pin = Pout (max)

$$I_{pk} = \frac{Pin}{Vin/\sqrt{2}}$$

   Or, $I_{pk} = \frac{90}{220/\sqrt{2}} = 0.5785$ amps

   Ripple current is assumed to be 20% of the peak inductor current.

   $\Delta I = 0.2 \times 0.5785 = 0.16$ amps

At I_{pk}, duty factor (D) is given by:

$$D = \frac{V_{out}}{V_{in(RMS)}} = \frac{135}{\frac{220}{\sqrt{2}}} = 0.87$$

Hence, inductance L is given by:

$$L = \frac{Vs \times D \times (1-D)}{\Delta I \times f} = 1.1 \ mH \qquad\qquad \text{[1], [4]}$$

5.4 Selection of Output Capacitor:

Peak to peak ripple voltage of the capacitor is assumed to be 20mV.

$$C = \frac{\Delta I}{8f \times \Delta V_c} = 10 \ \mu F \qquad\qquad \text{[4]}$$

CHAPTER 6

RESULTS AND DISCUSSIONS

6. RESULTS AND DISCUSSIONS

6.1 Powersim (PSIM) Software

PSIM provides an ultimate simulation environment for power conversion and control. It is mainly designed for power electronics, motor drives, analog and digital control, magnetics and dynamic system studies. It enables fast simulation and it is quite user-friendly.

The PSIM simulation environment includes the PSIM Circuit Schematic, the Simulation engine and the SIMVIEW for viewing and analyzing the waveforms. The PSIM schematic program is highly interactive and user-friendly in building the circuit as well as editing it.

The PSIM software has been used for carrying out all the simulations and analysis of the waveforms so obtained in the thesis.

6.2 SIMULATION RESULTS

Firstly, simulations are done using passive networks for different positions of filter capacitors and inductors. For all the passive circuits, RLC load has been used and the position of the filter has been shuffled to observe the variations in the input and output voltages and currents and the amount of distortions present in them.

Further, improvement of power factor is taken care of in the subsequent circuits where feedback loops are employed using analog circuits. A digital circuit implementation has also been carried out using UC3854 chip but it is observed that the power factor is very low. Hence, we are finally concerned with PFC using Analog circuits.

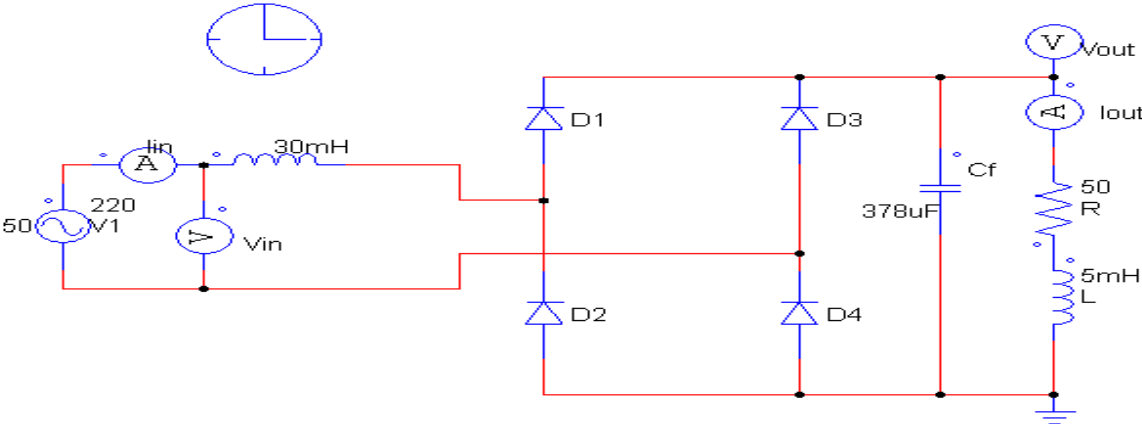### 6.2.1 Passive PFC using a Rectifier with AC side inductor

Fig 6.1: Circuit showing Passive PFC using an Inductor in the Input side
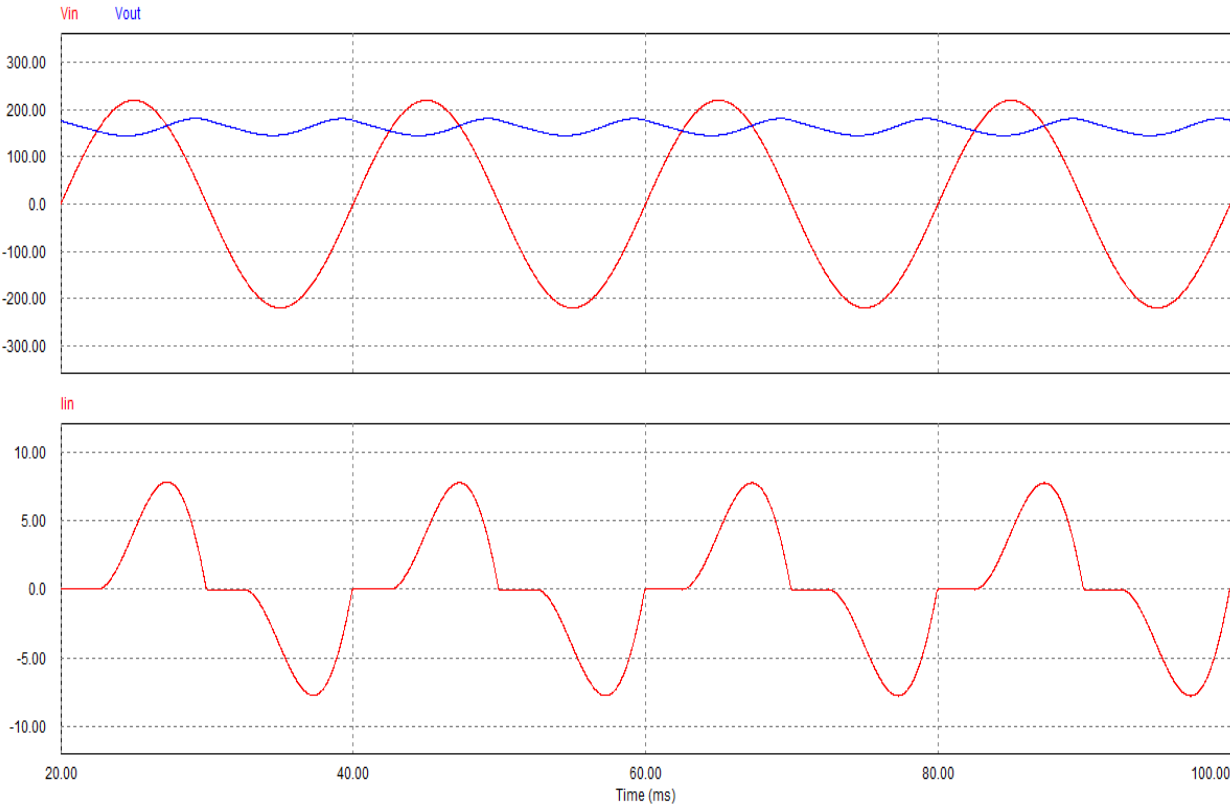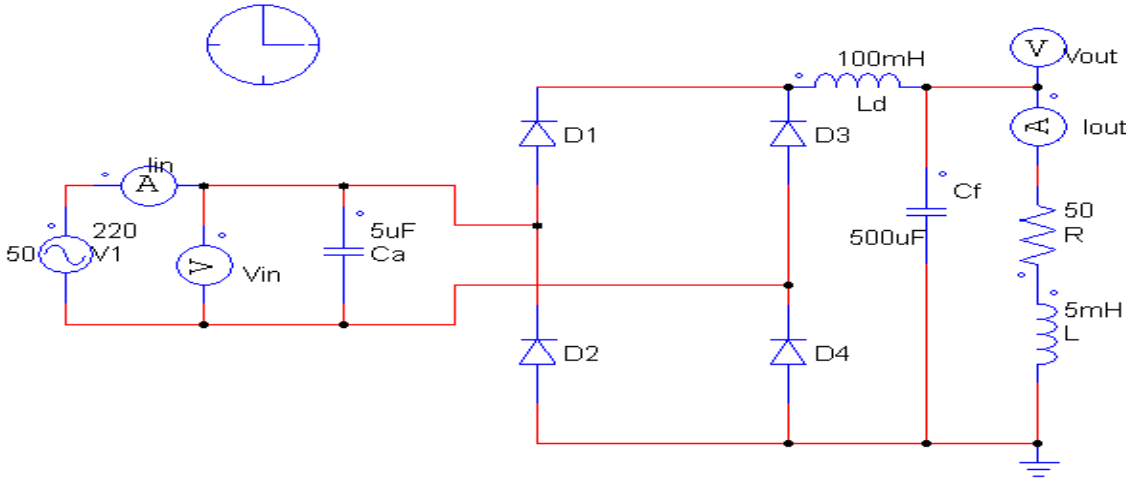

Fig 6.2: Input Voltage and Output Voltage, Input Current for inductor used in AC side where, L_a=30mH, C_f=378uF, L=5mH and R=50 ohms.

6.2.2 Passive PFC using a Rectifier with DC side inductor

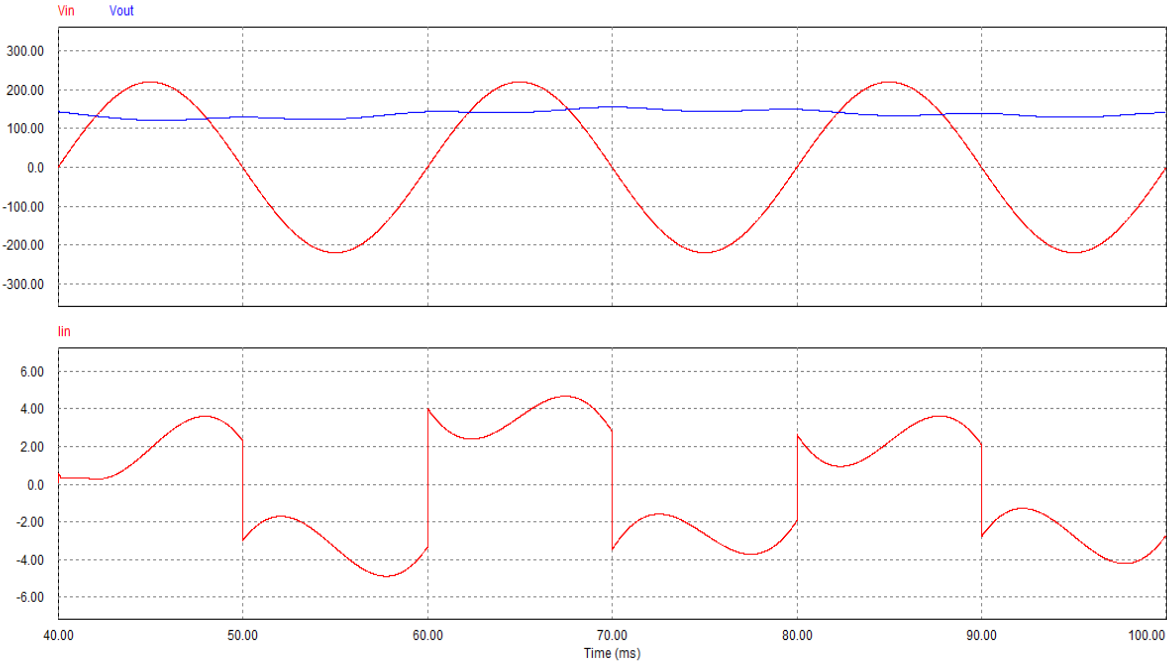Fig 6.3: Circuit showing Passive PFC using an inductor in the DC side

Fig 6.4: Input Voltage and Output Voltage, Input Current for inductor used in DC side where, L_a=30mH, C_f =378uF, L=5mH and R=50 ohms.

6.2.3 <u>Passive PFC using a Rectifier with LC Filter in input side and R- load</u>
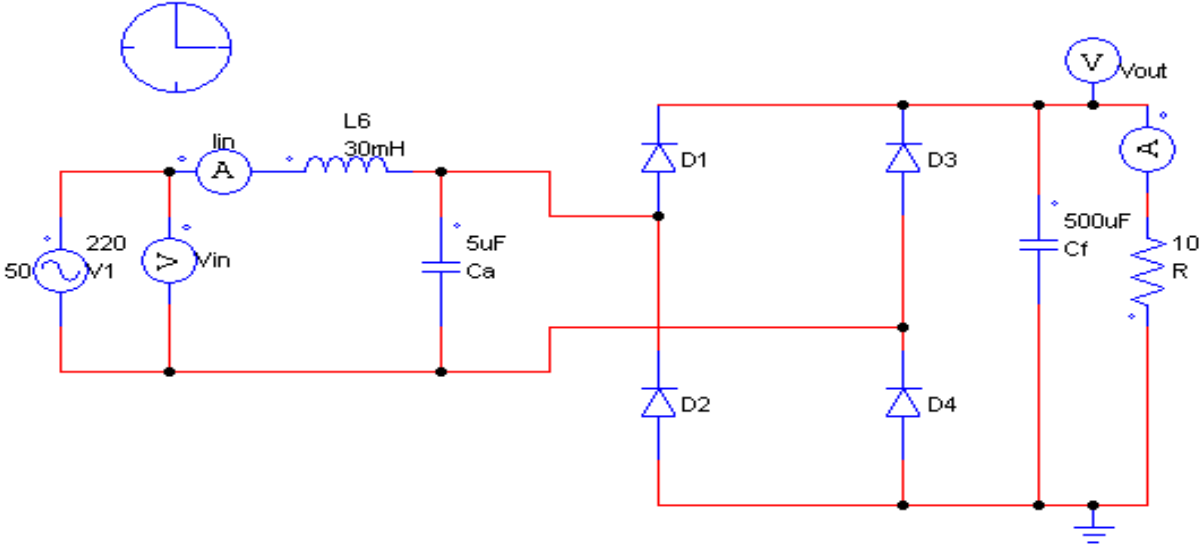

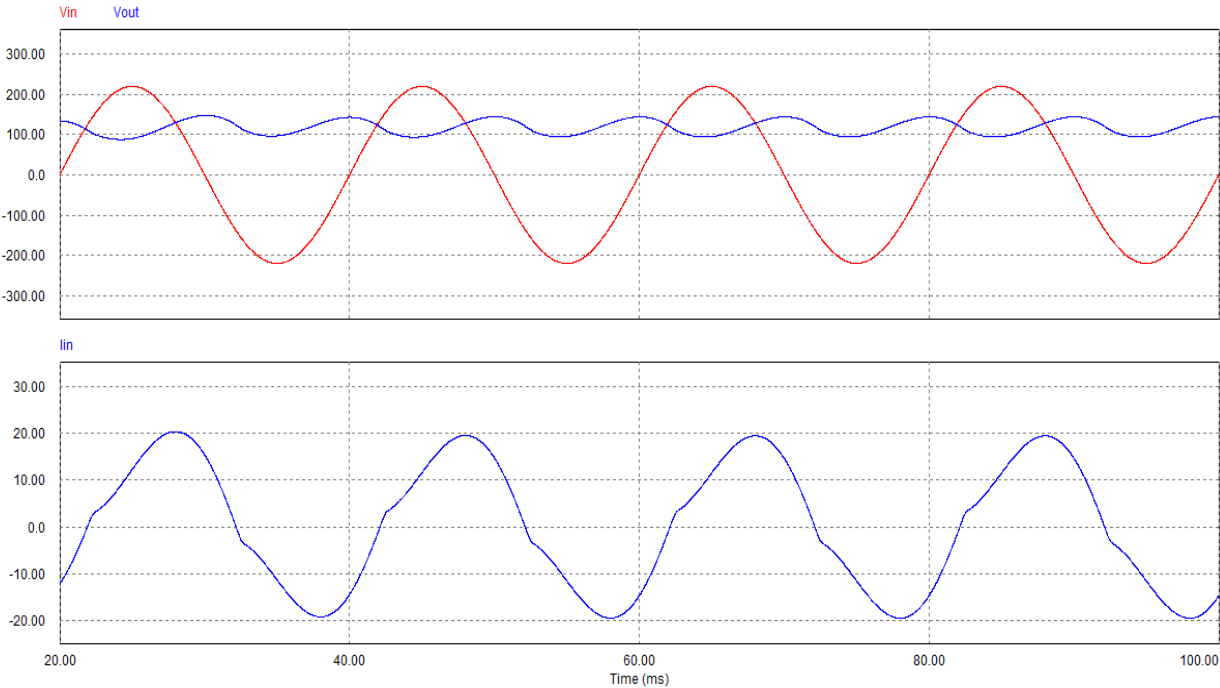Fig 6.5: Circuit showing Passive PFC using an LC filter in input side

Fig 6.6: Input Voltage and Output Voltage, Input Current for LC filter used in input side where,

L_a=30mH, C_a=5uF ,C_f=500uF, and R=50 ohms.

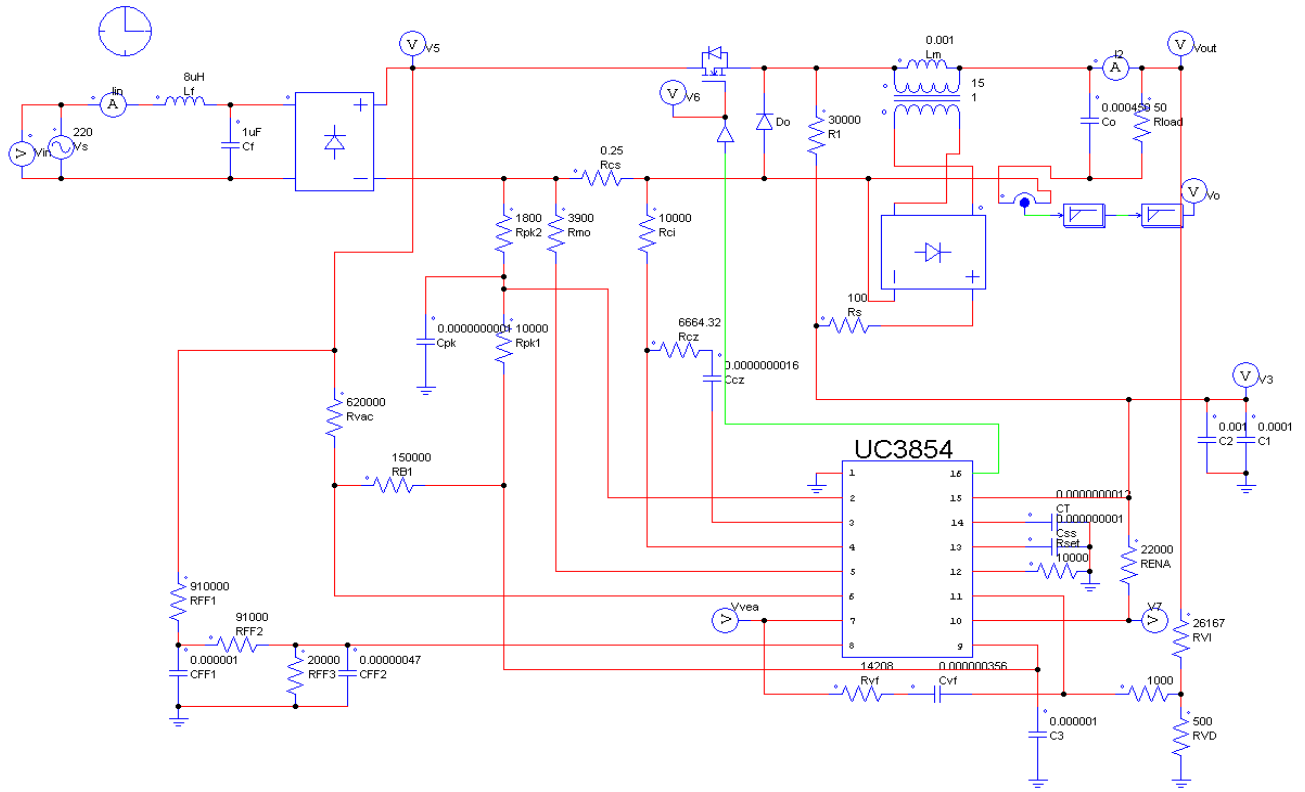## 6.2.4 <u>PFC using Digital Circuit implementation with UC3854 Chip</u>

Fig 6.7: PFC circuit using Digital Circuit implementation with UC3854 Chip
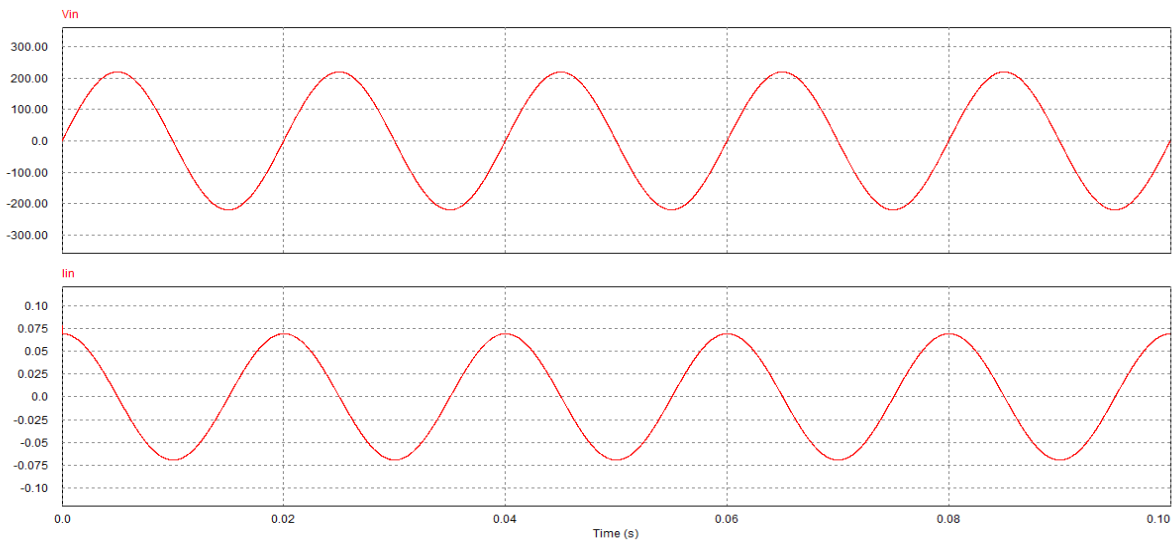

Fig 6.8: Waveforms showing Input Voltage and Input Current

<u>Observations obtained using UC3854 Chip:</u>

We observe that by using UC3854 chip in the digital circuit for power factor correction (PFC), although the nature of input current is similar to that of input voltage the phase difference between them is of considerable amount which results in very poor power factor.

So, we go for PFC using analog circuits. The following circuit is designed using analog devices with the Buck Converter for obtaining maximum power factor.
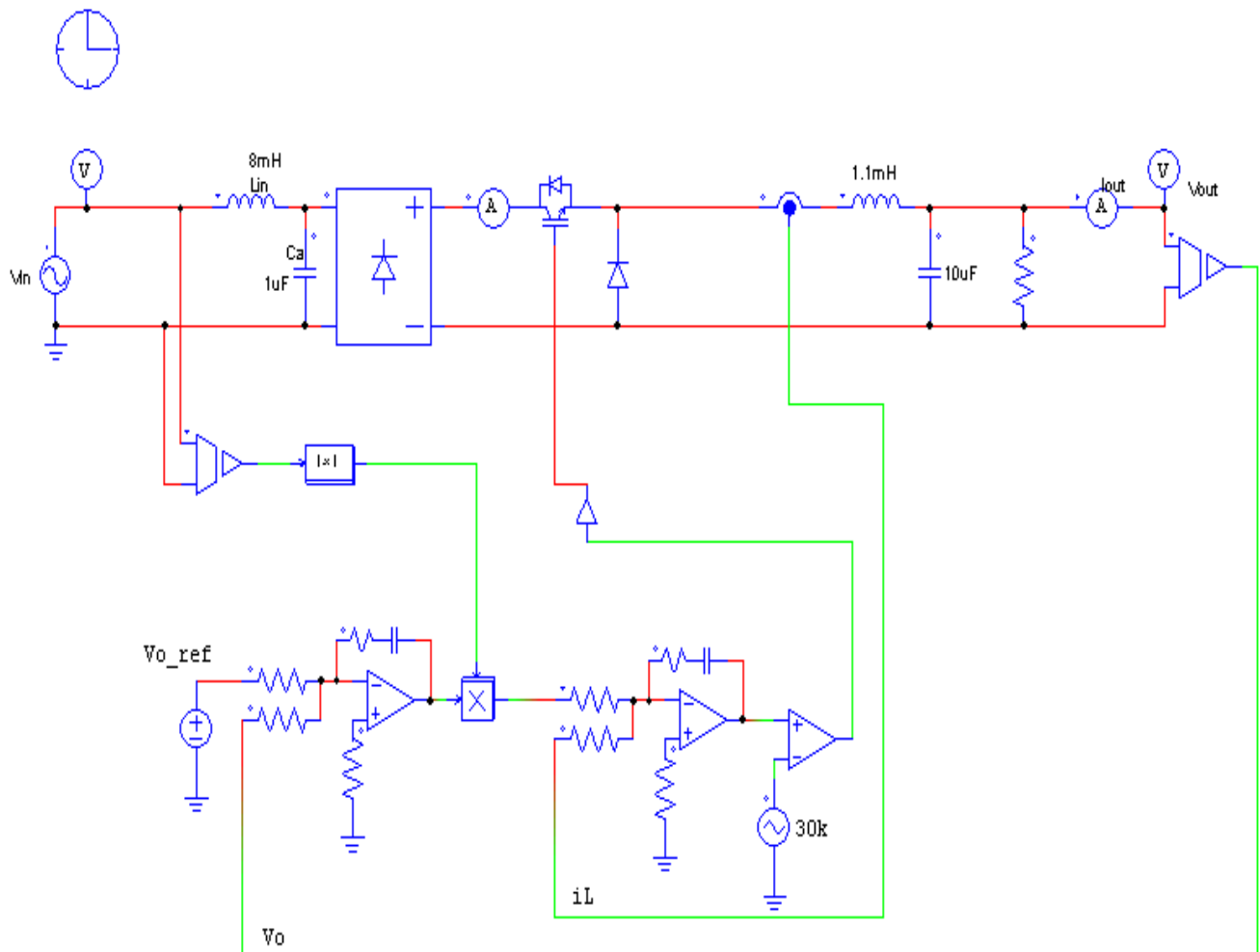
6.2.5 PFC using Average Current Mode Control (ACMC)

Fig 6.9: Circuit Diagram showing PFC using Buck Converter

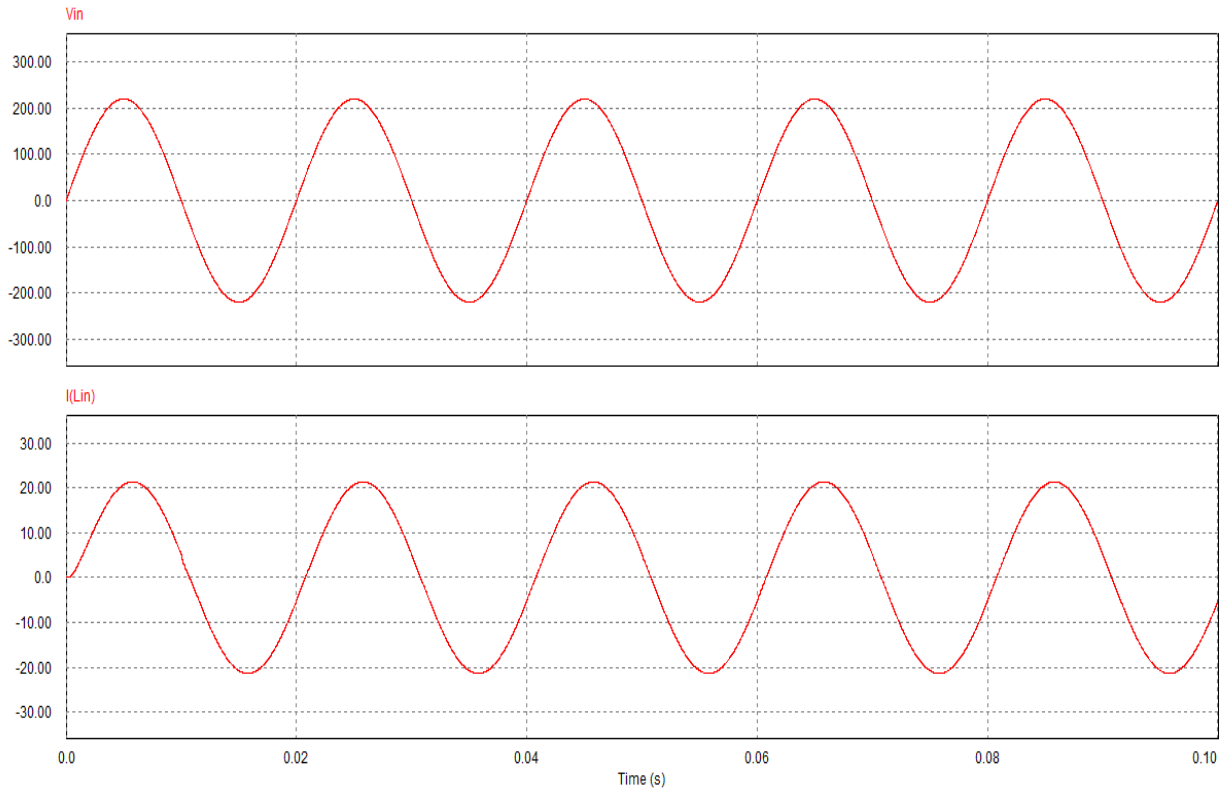Fig 6.10: Waveforms showing Input Voltage (Vin) and Input Current (ILin)

Simulation Results for the Active Power Factor Correction Circuit

Specifications of the Active PFC Circuit:

- Pout (max): 90W

- Input Voltage (V_{in}): 180-250Volts AC (peak)

- Line frequency: 50Hz

- Output voltage (V_{out}): 110-155Volts DC(rms)

- Load Resistance = 10 ohms

- Inductor value =1.1mH

- Output Capacitor = 10uF

Table 6.11: Simulation results for the 90W Active PFC Circuit

SL.No.	Input Voltage (V_{in}) in volts	Output Voltage (V_{out}) in volts	Power Factor
1)	180	110.135	0.97236
2)	190	117.13	0.96455
3)	200	122.23	0.96203
4)	210	129.87	0.96029
5)	220	134.326	0.95579
6)	230	140.692	0.95486
7)	240	147.695	0.95297
8)	250	154.698	0.95105

CHAPTER 7

CONCLUSION

<u>CONCLUSION</u>

The implementation of Average Current Mode Control (ACMC) with Buck 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 96% by using this technique.

Also, on varying the input voltage from 180 – 250 Volts, the output voltage did not vary by a big margin; rather the range of Output voltage obtained was in the range of 110 – 155 Volts DC. This shows that the line regulation obtained on varying the input voltage is very good.

Hence, the distortion produced in the line current in the electronic devices used for industrial and domestic applications due to harmonics and phase displacement caused by the non-linear loads connected in the grid can be nullified by Active Power Factor Correction circuits implementing ACMC with Buck converter using analog circuits.

<u>FUTURE WORK</u>

Through this project work we have made an attempt to analyze Active Power Factor Correction with the help of simulations. In future the hardware implementation of the PFC circuit can be done and its results obtained in real – time situations can be compared with the simulation results obtained in the thesis.

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