POWER FACTOR IMPROVEMENT OF SINGLE PHASE AC-DC SYSTEM USING PARALLEL BOOST CONVERTER

A thesis submitted in partial fulfillment in the requirements for the degree of

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IN

ELECTRICAL ENGINEERING

BY

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<u>CERTIFICATE</u>

This is to certify that the project entitled, "**POWER FACTOR IMPROVEMENT OF SINGLE PHASE AC-DC SYSTEM USING PARALLEL BOOST CONVERTER"**

Submitted by **Pema Rabden (Roll no-111EE0564)** is an authentic piece of project carried out by him under my supervision and guidance for the partial fulfillment of the requirements for the award of **Bachelor of Technology Degree** in **Electrical Engineering** at **National Institute of Technology, Rourkela**

To the best of my knowledge, the matter and content embodied in the project has not been submitted to any other University / Institute for the award of any degree / diploma.

Prof.A.K.Panda

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Upon the submission of my thesis report of my project on **"Power Factor improvement of single phase AC-DC system using parallel boost converter"**, I would like to extend my deep gratitude and my sincere thanks to my esteemed, honorable guide **Prof. A K PANDA**, HOD, Department of Electrical Engineering for giving me the opportunity to work in the field of power factor improvement. This project has given me enough scope of research oriented study. I really acknowledge and esteem his regarded direction and consolation from the earliest starting point to the end of this thesis. I am indebted to him for helping me correct the problem and supporting me throughout my project.

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I am thankful for the constant moral support of my parents and friends without which it would have been tough for me to complete this work.

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Abstract

Power factor in an AC electrical power system is described as the ratio of the actual power passing though the load to the virtual power flowing through the circuit or the cosine angle of the potential and charge of an AC circuit. A phase difference Ø exists between the potential and charge of an AC circuit and cosine which is called the circuit's power factor. Suppose we get an inductive circuit we generally get the lagging by the voltage and that will be called a lagging power factor. And suppose we get the capacitive circuit then the current will be leading by the voltage and that will be referred as a leading power factor.

The usage of power electronic system has reached to a new application stage that include residential, commercial, and aerospace and many others. Power electronic interfaces e.g. Switch Mode Power Supplies (SMPS) have proved to be superior over traditional linear power supplies. However their nonlinear behavior puts a question mark on their efficiency. The current drawn by the SMPS from the line is distorted resulting in a high Total Harmonic Distortion (THD) and low Power Factor (PF). Other adverse effects on the power system includes increased magnitudes of neutral current in three phase systems, overheating of transformers and induction motors etc.

Therefore there is a continuous need of power factor improvement and reduction of line current harmonics. A large range of PFC circuits have been proposed with diverse operating modes to solve the situation. These PFC circuits adjust the waveforms of the current in the input side so that the maximum power can be tapped from the supplies. For every equipment the load should try to match a resistive one as closely as possible, only then the PF will be near to unity as there will be reduction of reactive power in the circuit. The current in this situation is free from all the lower as well as higher order harmonics thus copies the input voltage waveform. So this causes the current in the circuit to be at the lowest possible value to do the same work. As a result, the losses associated with circuit are reduced. Hence the consumption in power is reduced greatly. Boost converter accomplishes this active power-factor correction (ACMC) in discontinuous as well as in continuous modes.

Simulation of a single phase bridge converter without using any converter is performed first. Then a current control circuit and a voltage control circuit were added to the boost converter which improved the input THD.

This project aims to develop a circuit for power factor improvement using two Boost converters connected in parallel. It is based on the power sharing method to improve the current quality and to reduce the switching losses. In this method current in one circuit has to keep up with the one in parallel to it.

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CHAPTER1: INTRODUCTION

1.1 POWER FACTOR:

Power factor in an AC electrical power system is described as the ratio of the actual power passing though the load to the virtual power flowing through the circuit or the cosine angle of the potential and charge of an AC circuit. A phase difference Ø exists between the potential and charge of an AC circuit and cosine which is called the circuit's power factor. Suppose we get an inductive circuit we generally get the lagging by the voltage and that will be called a lagging power factor. And suppose we get the capacitive circuit then the current will be leading by the voltage and that will be referred as a leading power factor.

In an electrical power system, a low power factor load draws greater current than a higher power factor load for the equivalent ratio necessary power passed.

Power factor provides a ratio which shows the effectiveness of the actual power utilized in the system. It is a measure of distortion of the line current and their phase change.

Power factor= Real power (average)/Apparent power

The virtual power is known as the multiplication of the rms value of current and voltage. We can describe the real power like the power of the circuit for doing work in some known interval of time.

LINEAR SYSTEMS:

For linear system, the load generally puts out clear sine voltage and current, so we can know about the Power factor jut by the change in phase of voltage and current.

I.e. PF=cos Ø

In a totally resistive circuital current and voltage graphs are in step (or in phase), if we reverse the polarity at the same interval for every cycle. The power getting into the load is utilized. A linear load never changes the structure of the graphs of the current, but it may differ the combined timing of the generated current and voltage.
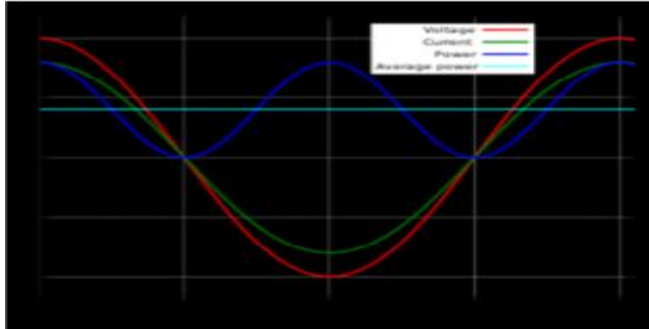
Purely resistive load waveform..

Some loads which are inductive like transformers and also motors intake power which is reactive and we get the lagging current waveform than the voltage. Capacitor banks which gives loads which are Capacitive produce extra power which is reactive and we get the leading current phase than the voltage.

Purely inductive load waveform

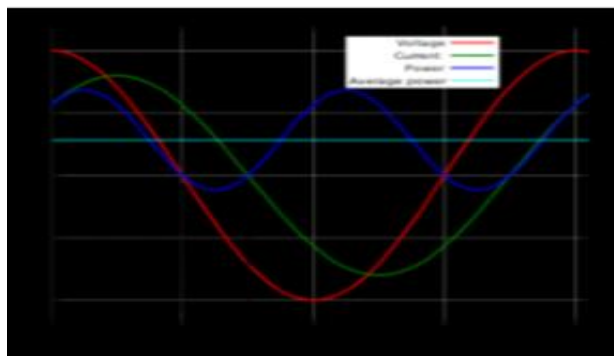The different applications for AC-DC converters are speed drives which are adjustable. Switched Mode Power systems (SMPS), UPS, etc. Diode rectifiers can be utilized for the applications of different Power Electronic devices which are in connection with the AC utility mains. We can get the non-linear nature of the Diode rectifier and due to this we get harmonics in the current line, so due to this the destruction of the power quality which in turn increase the various losses in the device. In the beginning the capacitors and the inductors were very costly and they were used or decreasing the harmonics. Active Power Line Conditioners (ALPC) that were utilized for decreasing the harmonics are switched hard, which causes low efficiency. There are the Boost converter topology in which there is a continuous conduction mode (CCM) is put in medium power AC/DC converter, as they provide a power factor which is nearly equal to unity if we see from the input side of the terminals which is in this case is AC.
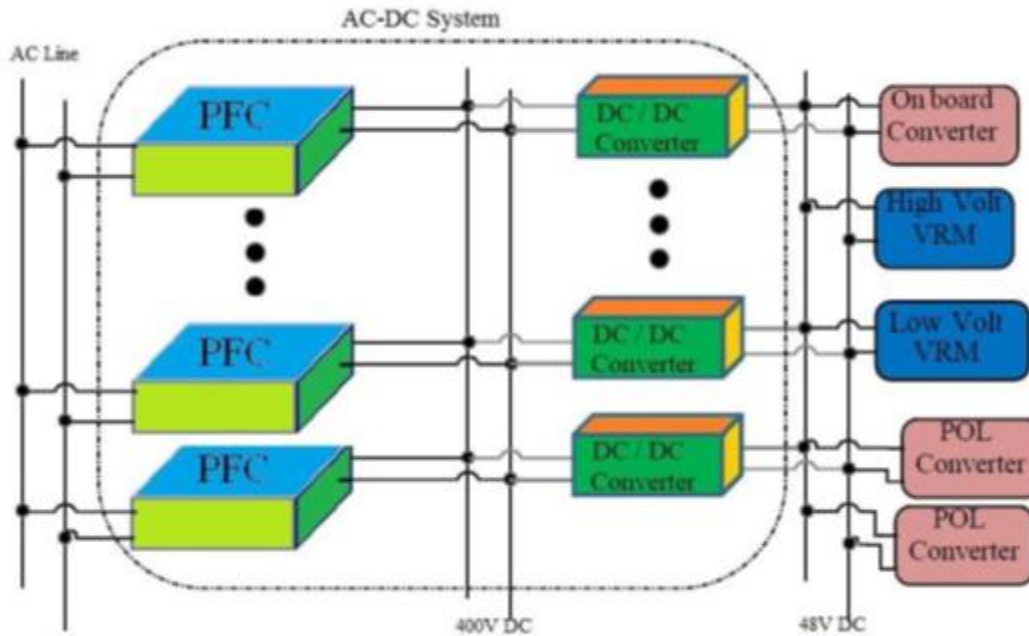
FIG-1. Block diagram regarding AC-DC system.

The power which is given in the AC line is the multiplicative product of the rms values of the voltage current signals.

We call this power "apparent power".

$$P_A = V_{rms}I_{rms}$$

Actual Power is provided by the product of the instantaneous current and voltage and then we are supposed to get the result by averaging the product.

$$P_R = \frac{1}{T}\int v(t)\, i(t)dt$$

Where,

$v(t)$= instantaneous voltage signal

$i(t)$= instantaneous current signal

1.2 HARMONICS:

As the non-linear interrelation of the voltage and current throughout the switching devices, harmonic is produced by each type of switching converters. We can also produce Harmonics by the equipment's which are conventional which includes:

1. Equipment that generates power (slot harmonics).

2. Induction motors (saturated magnetics).
3. Transformers (saturation happens due to over excitation).
4. Magnetic-ballast fluorescent lamps (arcing) and
5. AC electric arc furnaces.

These are the above mentioned devices that are responsible for the flow of the harmonic current and there are some devices which directly creates voltage harmonics.

1.3 THE PROBLEM OF POWER FACTOR IN SINGLE PHASE LINE COMMUTATED RECTIFIERS:

These are the following disadvantages of the Classical line commuted rectifiers:

1. A lagging displacement factor is produced with respect to the utility's voltage.
2. A considerable amount of input current harmonics is generated.

These are the aspects which somewhat affects the power factor as well as the quality of power.
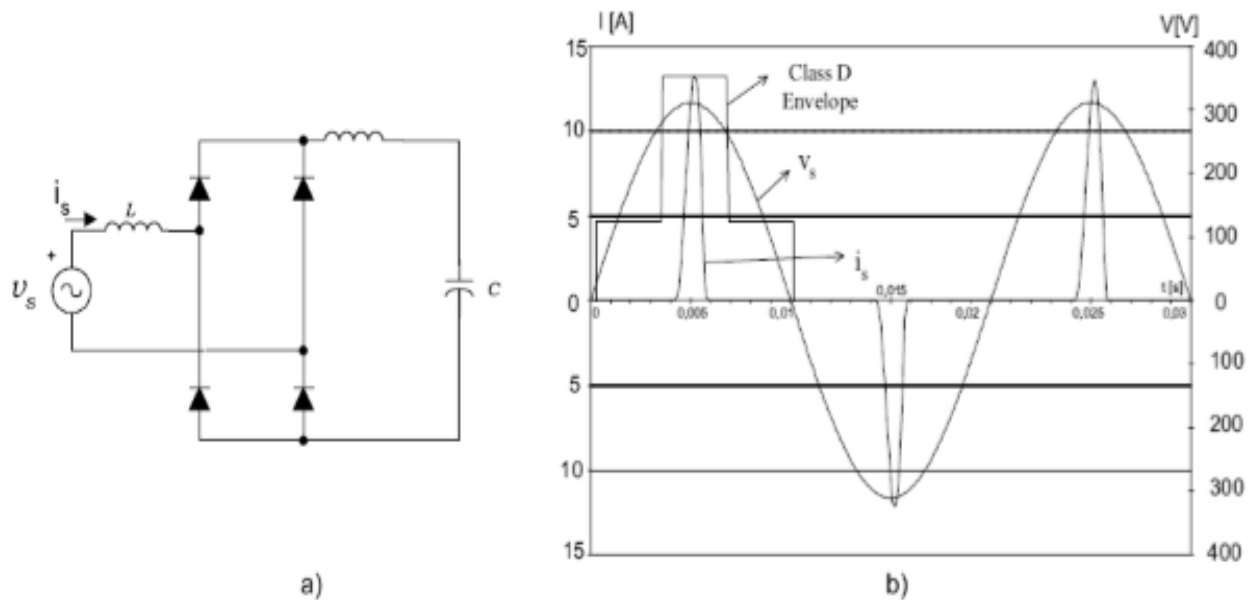
Fig.2: Single Phase Rectifier a) Circuit b) waveforms of input voltage and current

1.4 POWER FACTOR AND TOTAL HARMONIC DISTORTION:

The ratio of summation of rms values of current harmonics with the squared root mean value of the primary component of the current is called the Total harmonic distortion of the current.

$$THD = \frac{[\sum_{n=2}^{\infty} I_{nrms}^2]^{0.5}}{I_1}$$

So,

$$\frac{I_1}{I_{rms}} = \frac{1}{\sqrt{1 + THD^2}} = k_p$$

Where k_p is the distortion factor

So, the power factor's expression becomes

$$PF = k_p cos\theta$$

The table tells us the power factor and the percentage of the THD.This data which is shown in the table tells us whether the power factor is smaller compared to 0.7, the combined harmonics rms value is more than primary rms value.SO we can clearly see that the efficiency which is smaller than 50% as we know that the power which is delivered only at primary frequency.

TABLE 1

Power Factor versus percentage of THD

($\theta = 0$, $\cos\theta = 1$)

Power Factor	THD (in percentage)
0.5	174.21%
0.7	102.12%
0.9	48.53%
0.96	29.36%
0.98	20.41%
0.992	12.53%
0.995	10.34%
0.997	7.78%
0.999	4.58%
0.9992	4.40%
0.9996	2.73%
1	0.00%

Power Factor versus Percentage of THD

($\theta = 0$, cosθ=1)
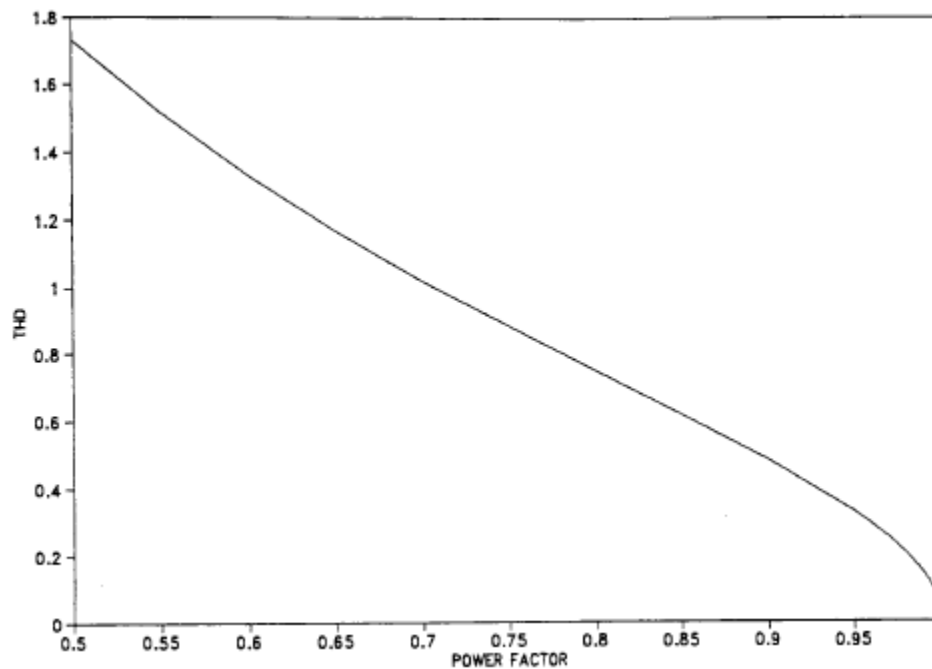
Fig 3: Graph between PF and THD(%)

1.5 STANDARDS FOR LINE CURRENT HARMONICS:

STANDARD IEC 1000-3-2:

1. The standard which we consider are those instruments whose current rating is up to. It uses 16A per phase and at the same instant it is supposed to be in connection to 50Hz/60Hz, 220-240Vrms if we are considering one phase system or 380-415Vrms if we are considering three phase system.

2. The types of the electrical equipment according to this standard are four which are A, B, C, and D.

3. Not taking the lighting equipment's consider only those equipment's which have rated power less than 75W.

CLASS-A:
Instruments only comes under class A which are not given in the remaining classes.

CLASS-B:
Class B contains the instruments which are portable that is the welders that are amateur in character.

CLASS-C:
Except the dimmers the remaining equipment's that are required for lighting purposes comes under class C.

CLASS-D:
The equipment's that are having an active input power less than or equal compared to 600W.
The important equipment that comes under this are PC, Monitors, TV sets.

STANDARD IEEE 519-1992:

It boosts the use of control harmonics in various power system for particular consumer and also in the form of utilities. The involved harmonics of the line current are known as the percentage of greatest usable load current I_L demand. If we reduce $\frac{I_{SC}}{I_L}$ it automatically reduces, which shows that the less firm grids have generally less limits.

POWER FACTOR CORRECTION

PASSIVE POWER FACTOR CORRECTION

ACTIVE POWER FACTOR CORRECTION

CHAPTER2: POWER FACTOR CORRECTION

2.1 PASSIVE POWER FACTOR CORRECTION

Harmonics current is controlled in an easiest possible way with the help of a designed filter which passes through only at line frequency (50 or 60Hz). Harmonic currents are pressed down to make the non-linear instruments seems linear. Power factor that can be corrected with the use of capacitors and inductors which are passive devices. These filters are basically called passive filters because they are passive devices.

A passive PFC circuit needs just some basic devices to level up the output ratio that is efficiency, but they are big because of their working at the line power frequency.
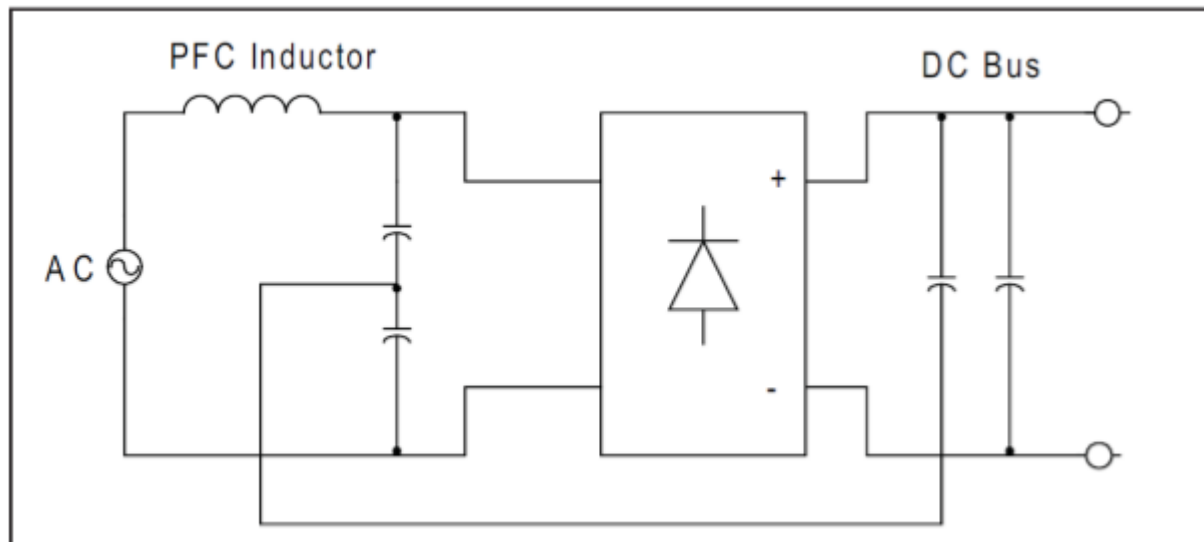

Fig 4: A passive PFC circuit.

The basic ways for improving passive power factor is by using:

1. Inductive input filter.
2. Resonant input filter.

2.1.1 INDUCTIVE INPUT FILTER

Inductive input filters are not totally same from capacitive input filters because of the added inductor in it. Capacitor voltage in capacitive filter is charged and also to a maximum input voltage.

The rectified inductive filter's voltage is averaged over half the period of source voltage i.e. $\frac{\pi}{\omega}$.

The increase in the power factor is happened with the help of the inductive input filter which is dependent on the inductor L's value and the filter load R's value. The inductor behaves like a storage material (energy storing material) and covers the non-regular parts in the current pulses and supports in providing a regular waveform. The inductor current is always not in phase with the voltage wave form so, this idea cannot provide a complete power factor.

The working of inductive input filter takes place in two modes which are-

1) continuous conduction mode (CCM) ;
2) Discontinuous conduction mode (DCM).

The time taken by the current for conduction through the inductor is dependent on the inductor value. The consumed time for conduction will increase if the value of the induction increases and the consumed time will decrease if the induction value decreases.
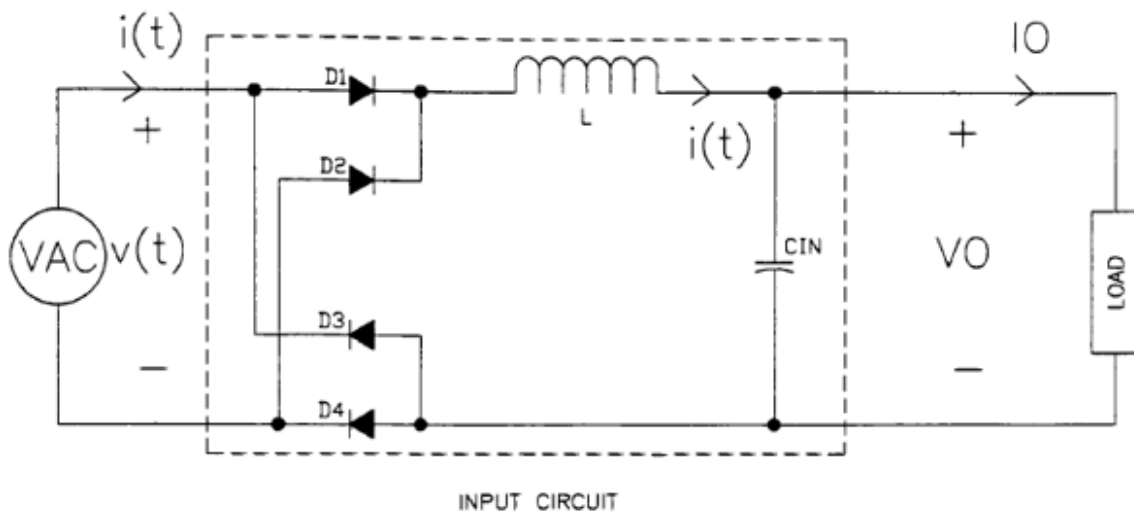

Fig 5: Rectifier circuit using inductive input filter

2.1.2 RESONANT INPUT FILTER

A series resonant network is created by the inductor/capacitor. This series resonant network forces the current to flow only at the filter resonance frequency. The maximum current flows in the circuit

only when the inductive reactance is equal to the capacitive reactance and this is achieved only at the resonant frequency.

The resonant frequency and the characteristics impedance define the resonant input filter, given by the expression

$$\omega_R = \frac{1}{\sqrt{LC}}$$

and

$$Z_R = \sqrt{\frac{L}{C}}$$

To get the maximum power factor the input line frequency and the resonant frequency are both made same.

$$\omega_R = \omega$$

The output DC voltage of the storage capacitor gives the DC current in load designed as R.
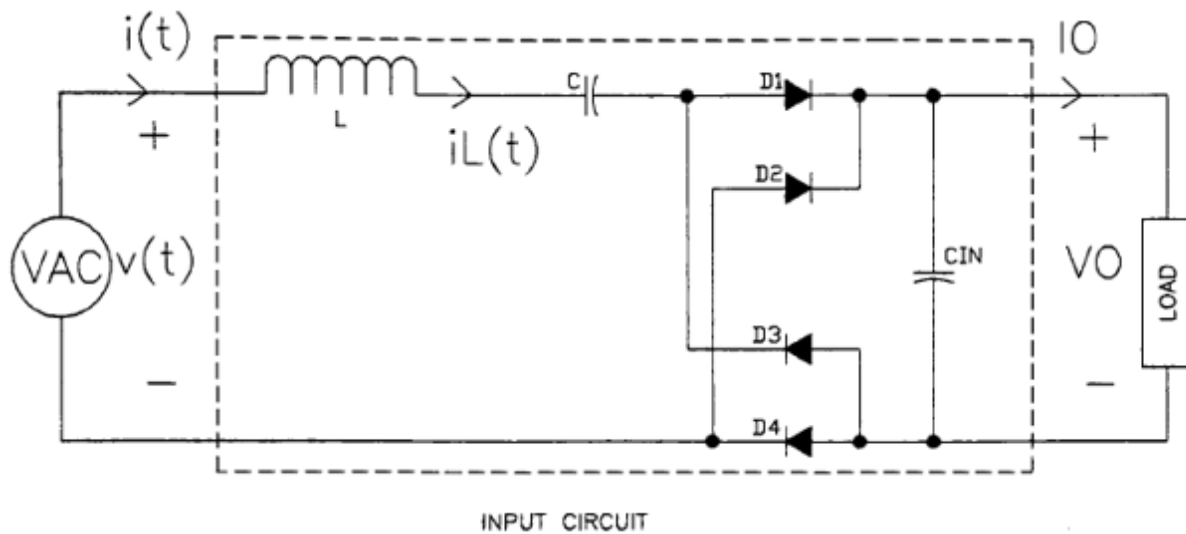

Fig 6: Rectifier circuit using resonant input filter

2.2 ACTIVE POWER FACTOR CORRECTION

An active power factor improvement is the finest method to improve rise the power factor in power drives. In this method we use a boost converter and we place it in the middle of the bridge rectifier and the main input capacitors. The converter establishes a constant DC output bus voltage and attains a current which is in similarity with and at the equivalent line voltage frequency.

The active PFCs trims the waveform for eliminating all the unnecessary harmonics by transforming the current put out from the line power at the converter's operating frequency. Out of all the topologies the most efficient as PFC converter is Boost converter. By analyzing all the topologies Buck converter is most disadvantageous because it needs extra input filter to eliminate the operating pulsating input current's frequency material. The Buck-Boost and fly back converters are generally utilized in less energy devices and is generally not suitable for greater power usages in which the improvement of factor correction is essential.
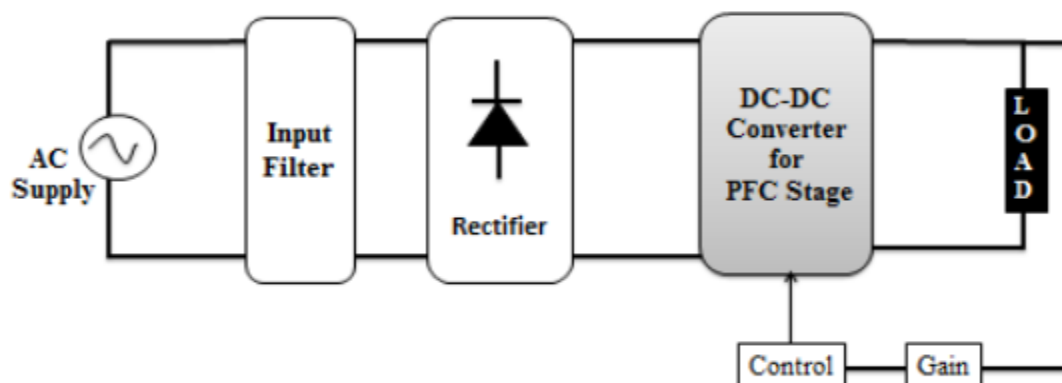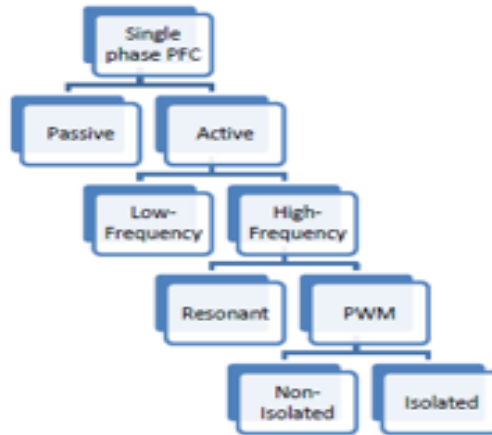

Fig 7: Block diagram of active PFC technique

Fig 8: Different types of single phase PFC topologies

ACTIVE PFC FUNCTIONS:

1. Modelling of Active wave of the input current.
2. Trimming high operating frequency.
3. The source current's Feedback sensing for waveform control.
4. Regulation of output voltage by Feedback control.

DC-DC CONVERTER

BASIC CIRCUIT TOPOLOGIES OF ACTIE POWER FACTOR CORRECTOR

WORKING PRINCIPLE OF BOOST CONVERTER

TRANSFER FUNCTION OF BOOST CONVERTER

CHAPTER 3: DC-DC CONVERTERS

Power electronic converters are normally used to convert electricity from one form to other forms. They form an interface between source and load side.

High-frequency active PFC circuits are used for power factor correction. If a proper control method is used to shape the input currents, any DC-DC converter can be used for power factor correction.

The DC-DC converters can operate in Continuous Inductor Current Mode (CICM), where the inductor current never reaches zero in one switching cycle or Discontinuous Inductor Current Mode (DICM), where the inductor current is zero during the intervals of the switching cycle.

Various types of control techniques are used to control the inductor current in Continuous Inductor Current Mode. Some of the techniques used are (1) Peak Current Control (2) Average Current Control (3) Hysteresis Control (4) Borderline Control. The average mode control technique is specifically developed for PFC boost converters and is analyzed here.

3.1 BASIC CIRCUIT TOPOLOGIES OF ACTIVE POWER FACTOR CORRECTOR

The basic circuit topologies of active PFC converter:

1. Buck corrector
2. Boost corrector
3. Buck-Boost corrector
4. Cuk, Sepic and Zeta correctors

Boost rectifiers which is one of the most important high power factor rectifier is used. It is obtained from a classical non-controlled bridge rectifier with the addition of transistor, inductor and diode.
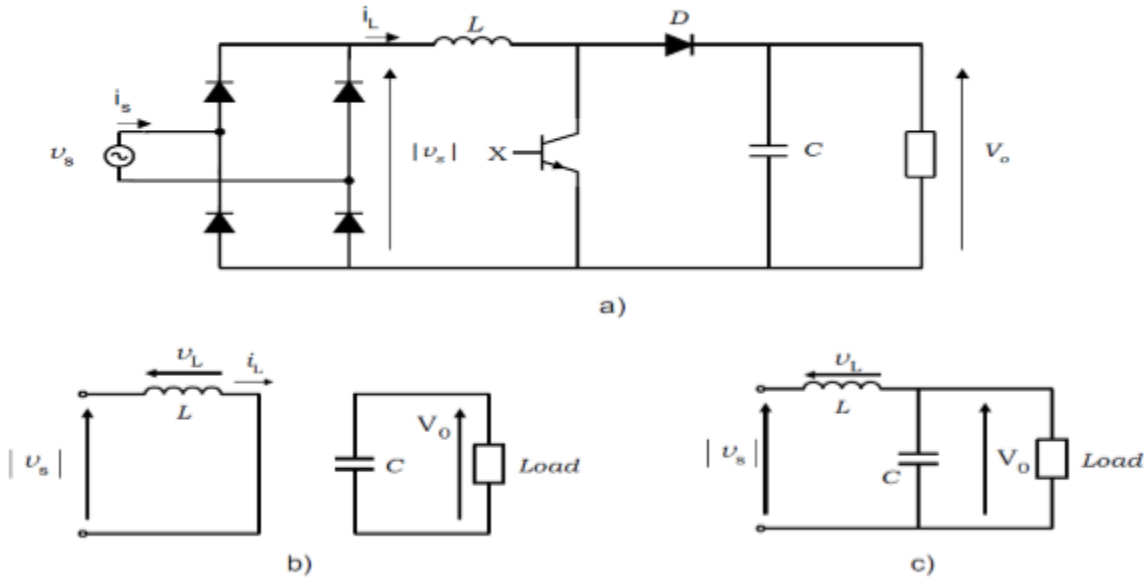
3.2 WORKING PRINCIPLE OF A BOOST CONVERTER

Fig 9: On and off states of a Boost rectifier.

The input current i_s(t) can be controlled by changing the transistor conduction state. By giving appropriate firing pulse to the transistor it is switched on. The waveform of the input current can be controlled to follow a sinusoidal reference.
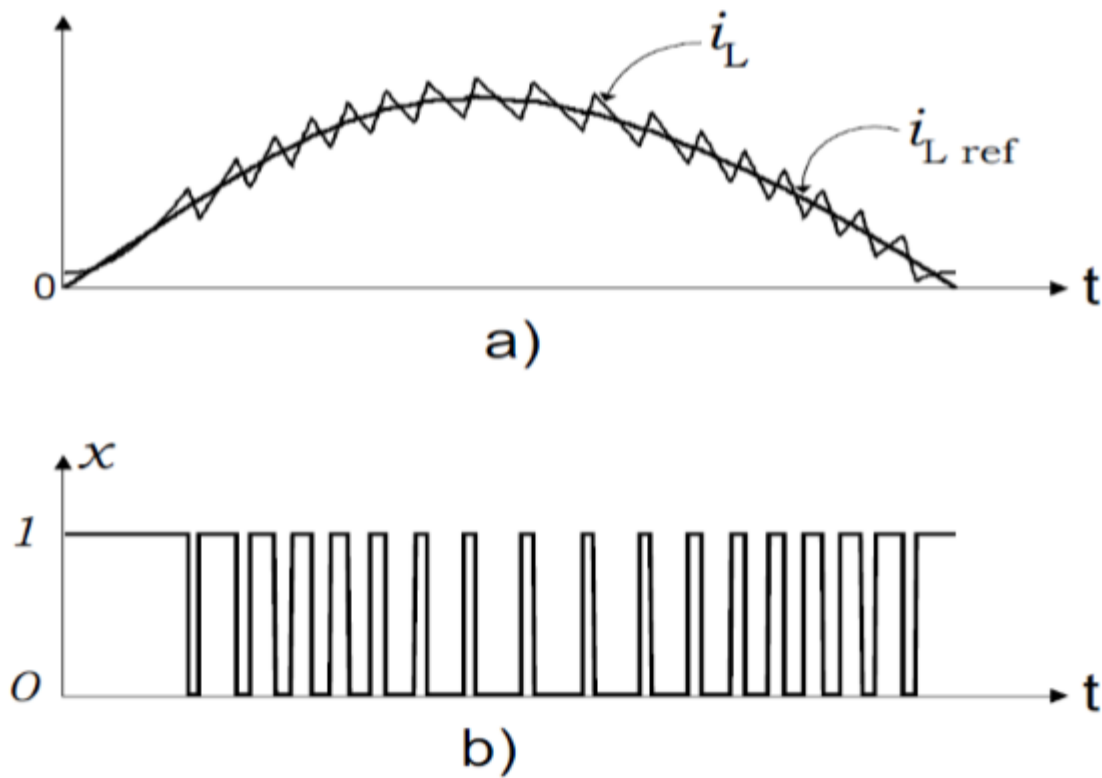
Fig 10 : Behavior of inductor current.

(a): Waveform

(b): Transistor T gate drive signal x

This figure above shows the reference inductor current i_{Lref} , the inductor current i_L, and the gate drive signal for transistor. At x=1the transistor is ON and it's OFF at x=0. The ON and OFF state of the transistor produces and increase and decrease in the inductor current i_L.

3.3 TRANSFER FUNCTION OF A BOOST CONVERTER

The line-to-output transfer function is obtained by taking fluctuations in duty cycle to be zero and hence:

$$G_{vg}(s) = \frac{\hat{v}(s)}{\hat{v}_g(s)}\bigg| \hat{d}(s) = 0$$

Its importance lies in designing of an output voltage regulator.

The control-to-output transfer function is achieved by taking the input voltage fluctuations to zero, and hence:

$$G_{vd}(s) = \frac{\hat{v}(s)}{\hat{d}(s)}\bigg| \hat{v}_g(s) = 0$$

This transfer function shows the influence on the output voltage by varying the control input.

Referring to the small-signal equivalent model, the transfer function is calculated as:

$$G_{vg}(s) = \frac{\hat{v}(s)}{\hat{d}(s)} = \frac{1}{D'} \frac{(R \| \frac{1}{sC})}{(R \| \frac{1}{sC} + \frac{sL}{D'^2})} = \frac{D'R}{D'^2R + s^2RLC + sL}$$

Comparing the standard form as:

$$G_{vg}(s) = G_{g0} \frac{1}{1 + \frac{s}{Qw_0} + (\frac{s}{w_0})^2}$$

We get,

$$G_{g0} = \frac{1}{D'}$$

$$Q = D'R\sqrt{\frac{C}{L}}$$

$$w_0 = \frac{D'}{RC}$$

Similarly,

$$G_{vd}(s) = \frac{V}{D'} \frac{(R\|\frac{1}{sC})}{(R\|\frac{1}{sC} + \frac{sL}{D'^2})} - I(\frac{sL}{D'^2}\|R\|\frac{1}{sC})$$

Comparing with standard formula,

$$G_{vd}(s) = G_{d0} \frac{1 - \frac{s}{w_z}}{1 + \frac{s}{Qw_0} + (\frac{s}{w_0})^2}$$

Where,

$$G_{d0} = \frac{V}{D'}$$

$$w_z = \frac{D'^2 R}{L}$$

CONTROL METHODS OF DC-DC CONVERTERS

PEAK CURRENT MODE CONTROL

AVERAGE CURRENT MODE CONTROL

CHAPTER4: CONTROL METHODS OF DC-DC CONVERTERS

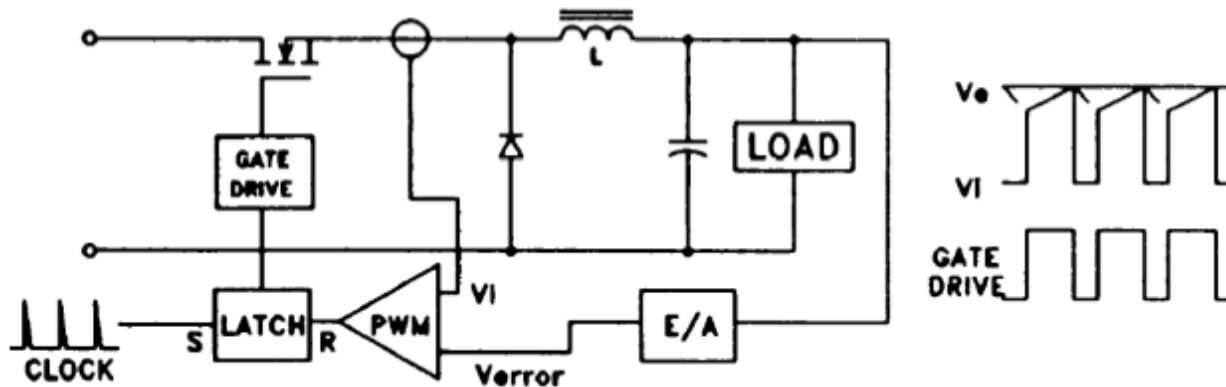## 4.1PEAK CURRENT MODE CONTROL

FIG 11: Peak Current Mode Control and its wave form

The work of the inner loop is to control the averaged inductor current. The switch current is equal to the inductor current during ON time. The peak current control is equivalent to the average inductor current control if the inductor ripple current is small or negligible. In Buck topology, the inductor current is in the output and in the Boost topology the inductor current is in the input. Thus the input current is controlled by the current mode control and thus desired waveform can be obtained.

In this method inductor current is compared with the reference current achieved from the outer control circuit. And when the value of instantaneous current is equal to the reference current the power switch is turned OFF by using a comparator.

4.1.1DRAWBACKS OF PEAK CURRENT CONTROL

(a) IMMUNITY TO NOISE IS POOR

Due to smaller instantaneous current compared to the reference current, the circuit is noisy. During the initial period more noises are observed in the circuit. Therefore voltage signal of low magnitude causing increment in the ripples associated with the circuit.

(**b**) **REQUIREMENT OF SLOPE COMPENSATION**

If the duty ratios exceeds 0.5 then the peak current control method is unstable thus results in ripples and harmonics. Therefore in order to make it stable a slope compensation is required. In a buck regulator, the slope of current through the inductor is $\frac{V_0}{L}$. But in a Boost regulator the slope of a current depends on the input voltage. This helps in reduction of distortions in the circuit and helps the circuit perform well.

(c) PEAK TO AVERAGE CURRENT ERROR

The low magnitude in the current results in the discontinuous waveform of the inductor current. While the peak current follows the sine wave current program and the average current does not follow it. In order to obtain low distortion the peak error/ the average error should be small. Therefore for this purpose a large inductor is required. Due to the use of large inductor, it makes the already poor immunity to noises worse.

(d) TOPOLOGY PROBLEMS

The peak current mode controls the inductor current in the output side. This method is used only in buck converters where the inductor configuration is on the output side of the circuit. Therefore this method is only applicable for buck topologies where as for other schemes it will lead to the control of the wrong current.

4.2 AVERAGE CURRENT MODE CONTROL

The average current mode control has two loops, the inner loop which controls the current and the outer loop which controls the voltage. This control method is applicable in higher switching frequency. Since this method is advantageous than the peak current mode control method, it is mostly used for the control of DC-DC converters and single phase power factor correctors.

Advantage of average current mode control over peak current mode control are as follows:

1. There is no requirement of compensation ramp.
2. At low frequency high DC gain is obtained.
3. Immunity to noises are better.
4. The increased DC gain at low frequencies are used for single phase AC-DC conversion using boost circuits.
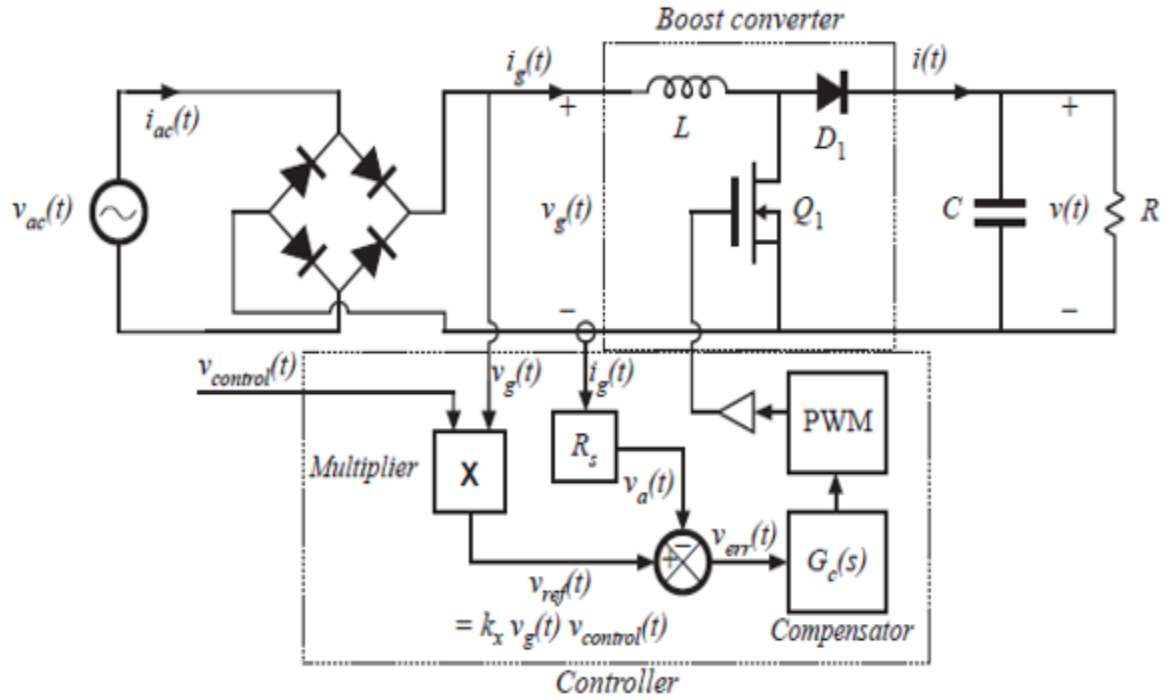
FIG 12: Average current control method.

According to figure above the current sensor gain is given by

$$V_a(t) = i_g(t)R_S$$

When the error signal is small

$$V_a(t) = V_{ref}(t)$$

And the expression for R_e is obtained as

$$R_e = \frac{R_S}{k_x v_{control}(t)}$$

PARALLEL CONNECTION OF TWO BOOST CONVERTERS

CIRCUIT MODELLING FOR DUAL BOOST PFC

CONTROL OF DUAL PFC

CHAPTER 5: PARALLEL CONNECTION OF TWO BOOST CONVERTERS

Parallel connection of two Boost converters give greater efficiency as their capacity is enhanced. But it can act in different unknown ways due to the non-linear nature of the system.

Designing this system aims to make the current share between the two converters. Practically two voltage sources are impossible to be connected in parallel connection. But it may work if a proper control circuit is designed. Hence the Average current mode control is used to solve this problem.

In this method one converter is phase shifted from its counterpart. The main advantages of this method are:

1. High reliability.
2. Cheap, portable and compact.
3. Greater reduction of ripples in input current.
4. Reduction in loses due to conduction.
5. The size of the inductor and capacitor is also reduced.

Boost converters are used in active power factor corrector. In recent years dual boost converters are used where two boost converters are connected in parallel. The circuit diagrams are shown below:
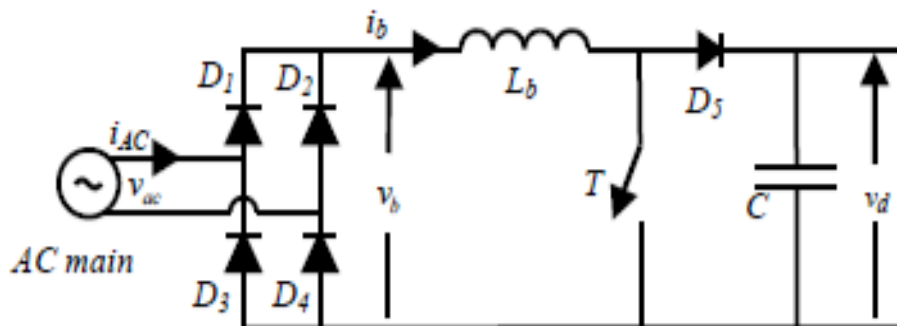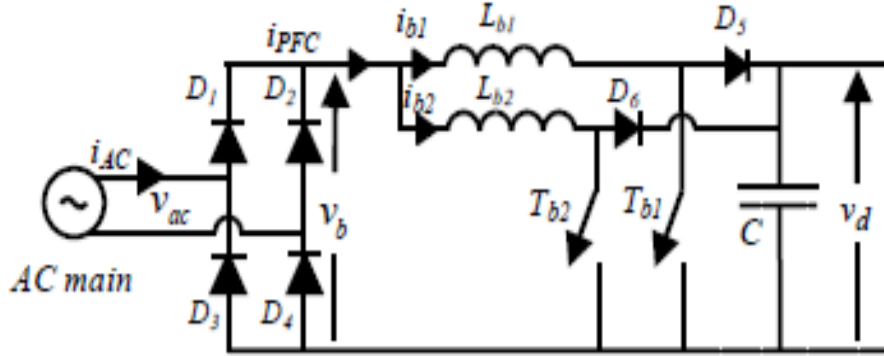

FIG 13 (a): PFC circuit.

FIG 13 (b): Dual Boost PFC circuit.

Parallel scheme is used here where the choke L_{b1} and the switch T_{b1} are for main power factor corrector and choke L_{b2} and switch T_{b2} are for active filtering. The filtering circuit improves the quality of line current reduces the switching losses. Switching losses are reduced because of different values of switching frequencies and current amplitude.

5.1 CIRCUIT MODELLING FOR DUAL BOOST PFC

Referring to figure 5(b) equations of voltages are found out:

$$v_g = L_{p1} \frac{di_{p1}}{dt} R_1 i_{p1} + f_{p1} v_d$$

$$v_g = L_{p2} \frac{di_{p2}}{dt} R_2 i_{p2} + f_{p2} v_d$$

$$i_{PFC} = i_{p1} + i_{p2}$$

Where,

$$v_g(t) = |V_g \sin(wt)|$$

$$f_{p1} = \begin{Bmatrix} 0 \ when \ T_{p1} = 1 \ (switch \ on) \\ 1 \ when \ T_{p1} = 0 \ (switch \ off) \end{Bmatrix}$$

$$f_{p2} = \begin{cases} 0 \text{ when } T_{p2} = 1 \text{ (switch on)} \\ 1 \text{ when } T_{p2} = 0 \text{ (switch off)} \end{cases}$$

$v_g(t)$, f_{p1} and f_{p2} are the main source voltage and Power Factor Correction commutation functions. Neglecting the inductor resistance the above equations are written as:

$$f_{p1} = 0 \rightarrow \frac{di_{p1}(t)}{d(t)} = \frac{v_g(t)}{L_{p1}}$$

$$f_{p1} = 1 \rightarrow \frac{i_{p1}(t)}{d(t)} = \frac{v_g(t) - v_d(t)}{L_{p1}}$$

$$f_{p2} = 0 \rightarrow \frac{di_{p2}(t)}{d(t)} = \frac{v_g(t)}{L_{p2}}$$

$$f_{p2} = 1 \rightarrow \frac{di_{p2}(t)}{d(t)} = \frac{v_g(t) - v_d(t)}{L_{p2}}$$

Where,

$$i_{p1} \geq 0 \text{ and } i_{p2} \geq 0$$

The Power Factor Correction current is achieved if the equation given below is satisfied:

$$v_d(t) > v_g(t)$$

5.2 CONTROL OF DUAL PFC

Under the condition $v_d(t) > v_g(t)$ the PFC currents i_{p1} and i_{p2} can be obtained. The derivative of the total PFC current can be controlled if the condition $v_d(t) > v_g(t)$ is satisfied.

$$\frac{di_{PFC}}{d(t)} = \frac{di_{p1}}{d(t)} + \frac{di_{p2}}{d(t)}$$

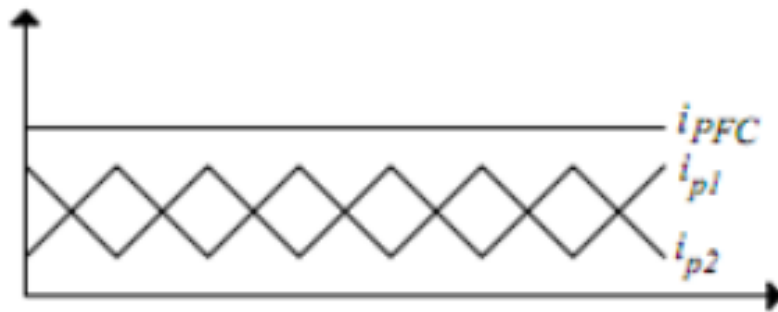FIG 14(a): Input currents of two interleaved PFC circuits.

FIG 14(b): Input currents of two interleaved PFC circuits in ideal working condition.
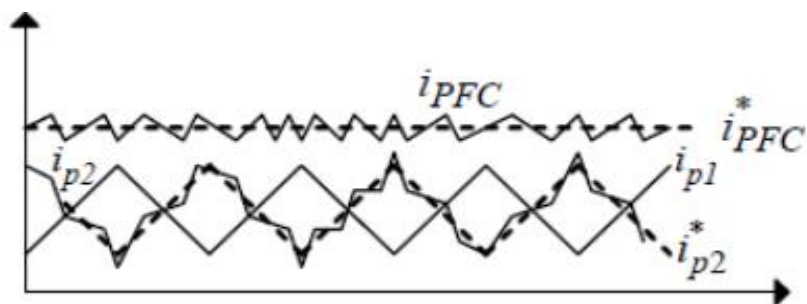

FIG 14(c): Input currents of two PFC circuits based on internal active filtering.

CHAPTER 6: RESULTS AND SIMULATION

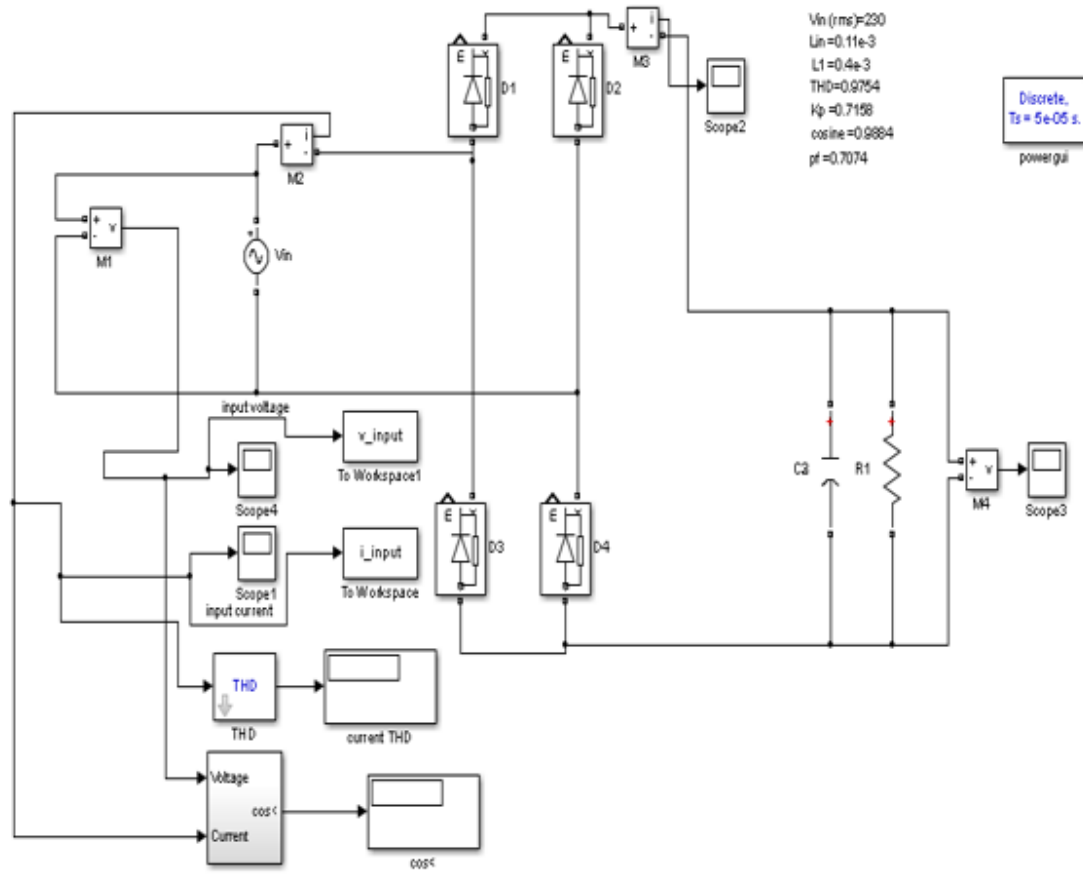## 6.1: CIRCUIT MODEL OF RECTIFIER WITHOUT ANY PFC CIRCUIT

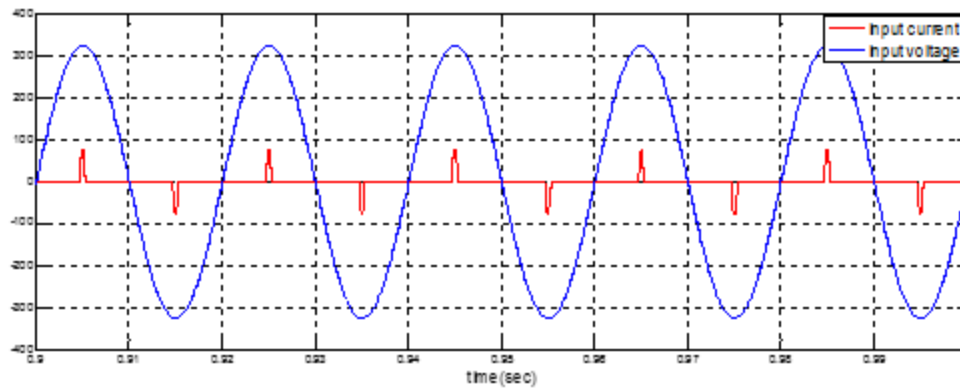FIG 15: SIMULATION BLOCK OF RECTIFIER CIRCUIT WITHOUT ANY PFC.

FIG 16: Plot of input voltage and input current vs time for rectifier circuit without any PFC circuit.
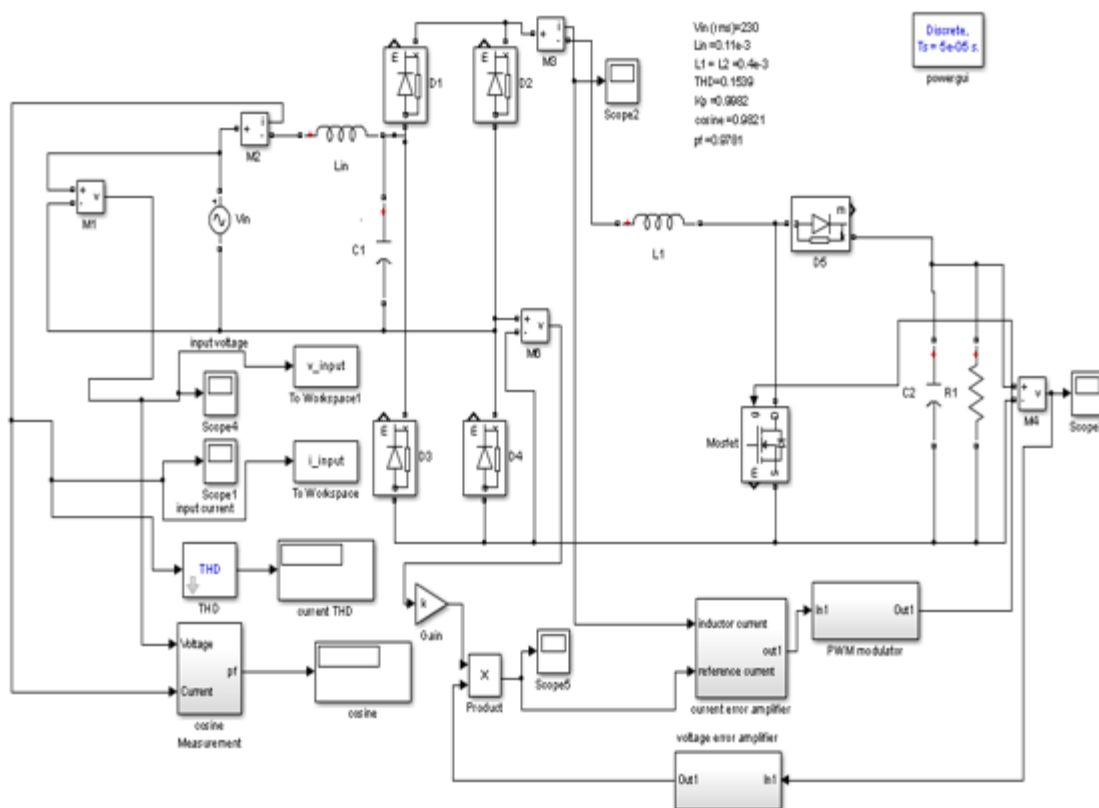

FIG 17: SIMULINK BLOCK OF RECTIFIER CIRCUIT WITH BOOST CONVERTER FOR PFC USING AVERAGE CURRENT MODE CONTROL.
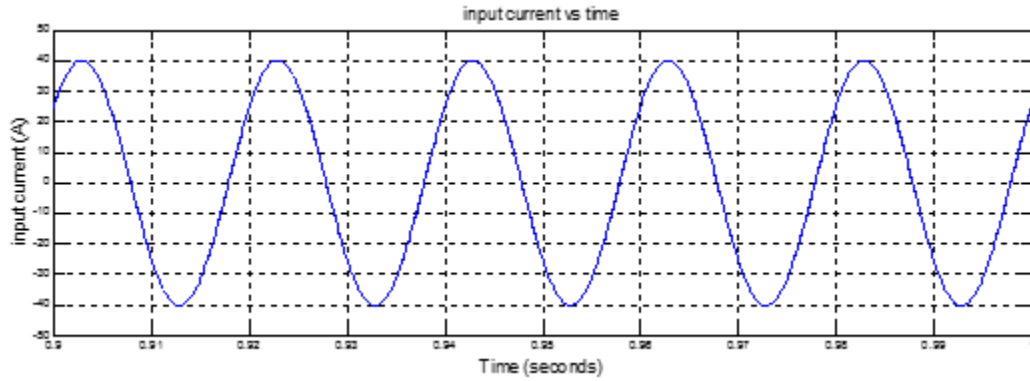
FIG 18: Plot of input current vs time for a rectifier circuit with Boost converter as PFC   circuit using average current mode control method.
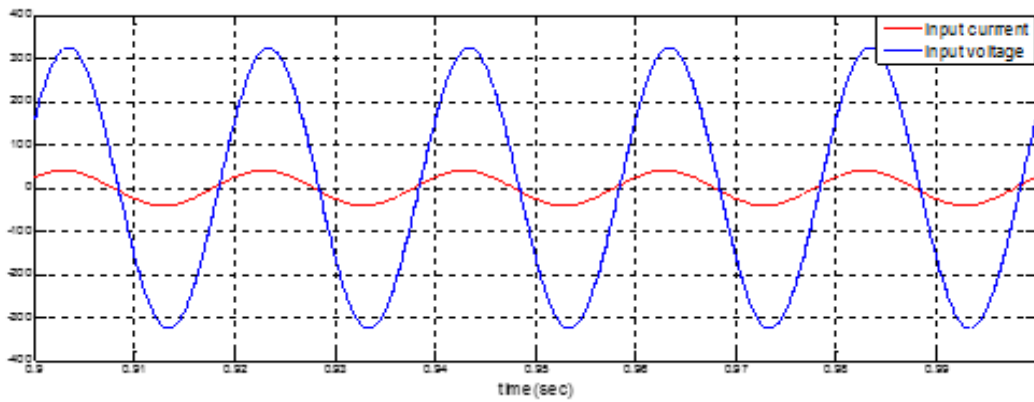

FIG 19: Plot of input voltage and input current vs time for rectifier circuit with Boost converter as PFC circuit using average current mode control method.
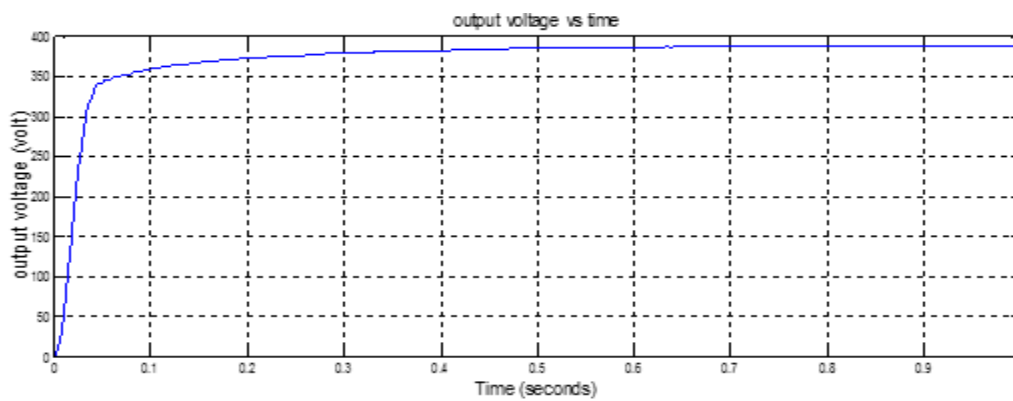

FIG 20: Output voltage for a rectifier circuit with Boost converter as PFC using average current mode control method.

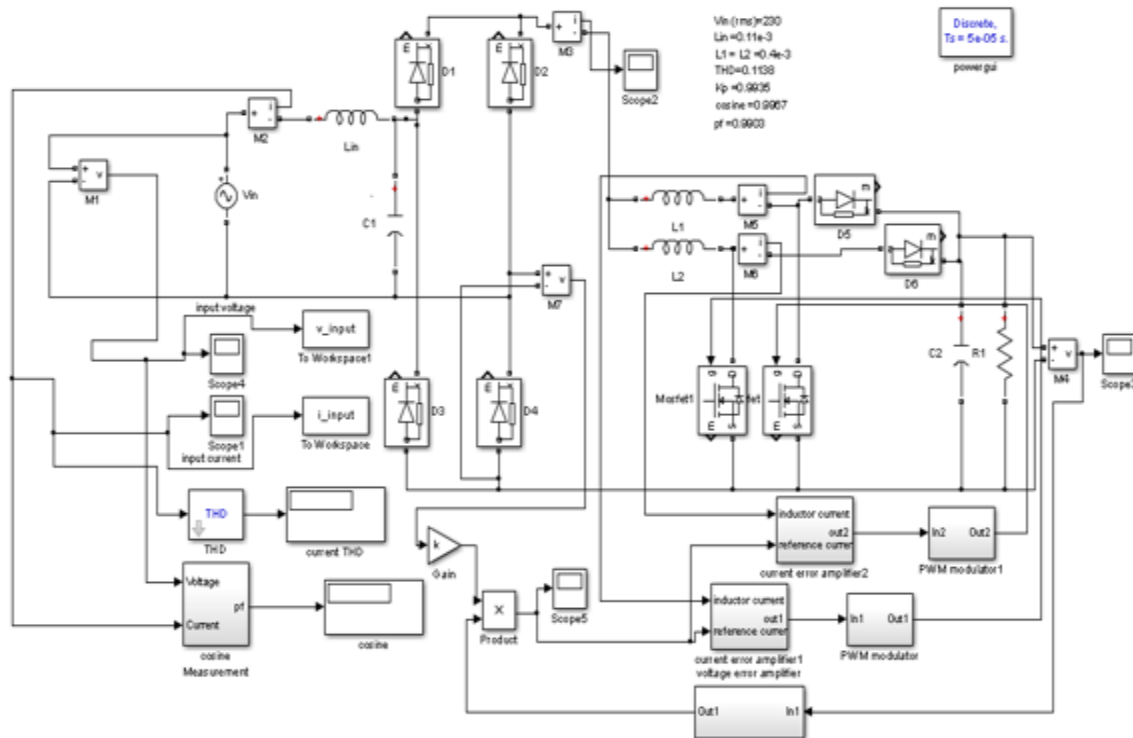## 6.2: RECTIFIER CIRCUIT MODEL WITH PARALLEL BOOST CONVERTER

FIG 21: SIMULINK BLOCK FOR RECTIFIER CIRCUIT WITH PARALLEL BOOST CONVERTER.
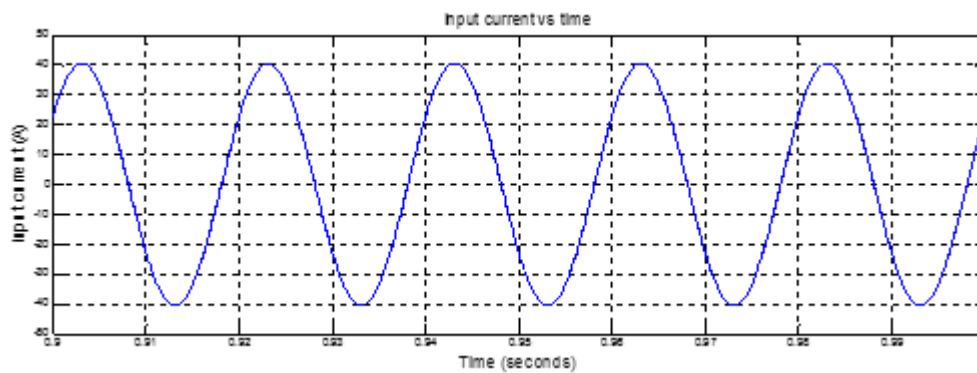

FIG 22: Plot of input current vs time for a rectifier circuit with parallel Boost converter.
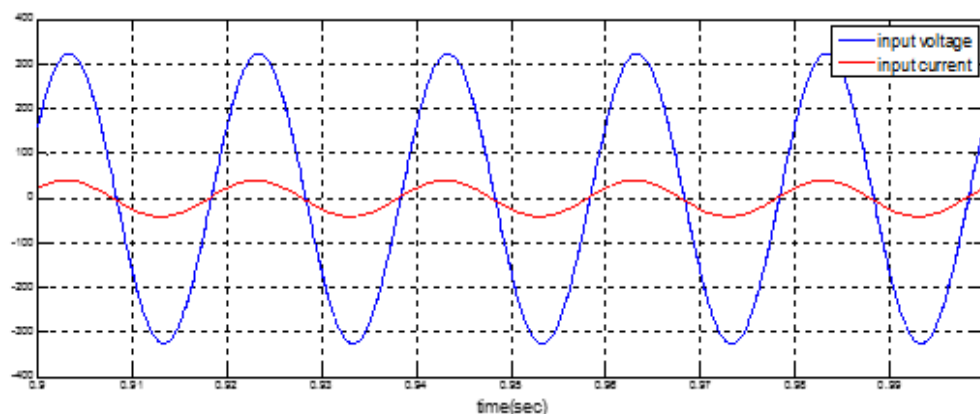
FIG 23: Plot of input voltage and input current vs time for rectifier circuit with parallel Boost converter.
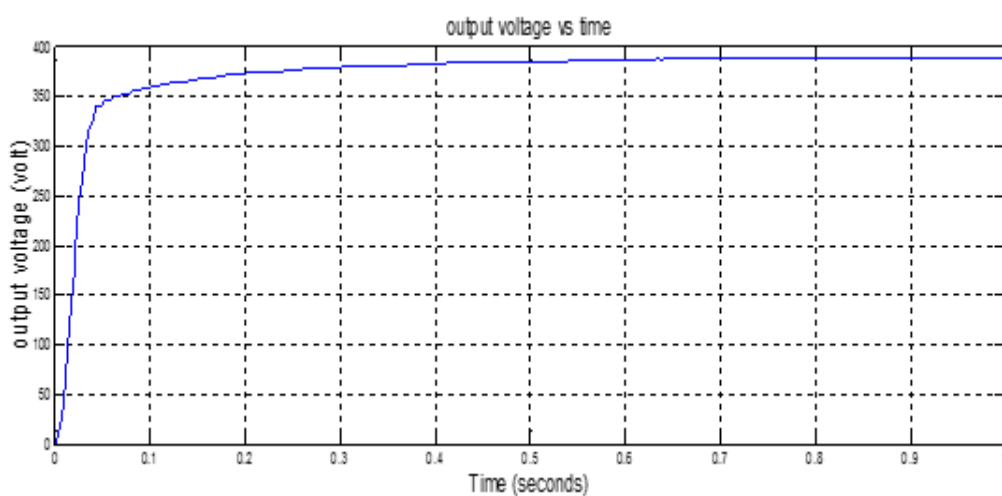
FIG 24 Output voltage for a rectifier circuit with parallel Boost converter.

6.3: CALCULATIONS

(a): RECTIFIER CIRCUIT WITHOUT ANY PFC CIRCUIT.

THD=0.975

Cosine=O.9884

Kp=0.7158

Power Factor=0.7074

(b): RECTIFIER CIRCUIT WITH BOOST CONVERTER FOR PFC

THD=0.1539

Cosine=0.9821

Kp=0.9982

Power Factor=0.9781

(c): RECTIFIER CIRCUIT WITH A PARALLEL BOOST CONVERTER FOR PFC

THD=0.1138

Cosine=0.9967

Kp=0.9935

Power Factor=0.9903

CONCLUSION

The main objective of my project was to improve the power factor with reduction of harmonics. The initial simulation started with the simulation of a simple rectifier circuit without using any control circuits or EMI filters. And this was followed by the simulation of rectifier circuit using control circuit based on average current mode control method. The current waveforms, power factor and THD was changed and was recorded accordingly. And later on a PFC circuit in which two Boost converters were connected in parallel and simulated. And average current mode control method was used as it keeps a close track with the input current program. Finally to make sure of improved Power Factor and Total Harmonic Distortion (THD), these parameters from three different circuits were calculated and compared.

By modelling the Boost converter using ACMC method, THD was recorded 0.1538 and by modelling Boost converters which were connected in parallel and using ACMC method, the power factor was improved with improved THD of 0.1137. The second Boost converter which is connected in parallel to its counterpart filters, the harmonics and the current quality were improved.

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