DIGITAL CONTROL OF ACTIVE POWER LINE CONDITIONER UNDER NON-IDEAL SOURCE VOLTAGES

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BONAFIDE CERTIFICATE

Certified that this project report titled "**DIGITAL CONTROL OF ACTIVE POWER LINE CONDITIONER UNDER NON-IDEAL SOURCE VOLTAGES** " is the bonafide work of **Mr.V.SURENDAR (0720105013)** who carried out the project work under my supervision. Certified further, that to the best of my knowledge the work reported herein does not form part of any other project report of dissertation on the basis of which a degree or ward was conferred on an earlier occasion on this or any other candidate.

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ABSTRACT

Due to the increasing use of power electronic equipment with nonlinear characteristics, the quality of the power gets decreased. This project work aims to minimize harmonics and to improve the power quality with the help of a shunt active filter. The thesis presents the design, analysis, and operation of Active Power Filter (APF) to eliminate harmonics.

A shunt active power filter (APF) application mainly for current harmonic elimination is proposed. The proposed simplified control method is based on instantaneous reactive power theory (IRP). A three-phase voltage source inverter bridge with a dc bus capacitor is used as an APF. It requires only measuring the source currents to reduce the number of current sensors (CSs) required in the conventional control approach. The source currents are exactly in phase with the line voltages and approximately in sinusoidal waveform after reactive power and harmonic compensation. Three hysteresis band current controllers are employed to derive switching signals to the shunt APF. A three-phase Diode rectifier with resistive-inductive loading is employed as a non-linear load. MATLAB/SIMULINK power system toolbox is used to simulate the proposed system. The Hardware Prototype has been done for Single Phase circuit. Using PIC16F877A Microcontroller with RL load the improvement is shown.

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CONTENTS

3 **ACTIVE POWER FILTER**

4 **CONTROL OF POWER FILTER**

5 **SIMULATION**

6 HARDWARE IMPLEMENTATION AND RESULTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

INTRODUCTION

1.1 INTRODUCTION

Since the rapid development of the semiconductor industry, power electronics devices have gained popularity in our daily used electrical house-hold appliances. Although these power electronics devices have benefited the electrical and electronics industry, these devices are also the main source of power harmonics in the power system. These power harmonics are called electrical pollution which will degrade the quality of the power supply. As a result, filtering process for these harmonics is needed in order to improve the quality of the power supply.

To solve the current harmonic related problems, passive filters connected in several circuit configurations present a low cost solution. However, passive filter implementations to filter out the current harmonics have the following disadvantages: Possibility of resonances with the source impedance, Supply impedance dependent system performance, fixed compensation.

In order to diminish the preceding disadvantages of the passive filters, active power filter (APF) have been worked on and developed in recent years.

Thus, active power filter seems to be a viable alternative for power conditioning to control the harmonics level in the power system nowadays. These harmonics interfere with sensitive electronic equipment and cause unnecessary losses in electrical equipment. Active power filters were initially proposed by Sasaki and Machida (Sasaki and Machida 1971) as a means of minimizing current harmonics. An active power filter uses a switching inverter to produce harmonic compensating currents. It is only with the recent advances in semiconductor technology that high-speed, high-power switching devices suitable for constructing active power filters have become available (Duke and Round 1993, Akagi 1996).

APF's consisting of voltage-source inverters and a DC capacitor have been researched and developed for improving the power factor and stability of transmission systems. APF have the ability to adjust the amplitude of the synthesized ac voltage of the inverters by means of pulse width modulation or by control of the dc-link voltage, thus drawing either leading or lagging reactive power from the supply. APF's are an up-to-date solution to power quality problems.

It is designed to be connected in parallel with the non-linear load to detect its harmonic and reactive current and then to inject a compensating current into the system. Therefore, the current drawn from the power system at the coupling point of the shunt APF will result in sinusoidal waveform.

1.2 OBJECTIVE

To design and implement a active power filter (APF) for reducing the harmonic distortion based on P-Q theory.

The p-q theory performs a transformation known as "Clarke Transformation" of a stationary reference system of coordinates $a - b$ - c to a reference system of coordinates α - β - 0, also stationary.

1.3 NON-IDEAL SOURCE VOLTAGES

The mains voltage was assumed to be an ideal source in the calculation process. However, in most of time and most of industry power systems, mains voltage may be unbalanced and/or distorted. In this, non-ideal mains voltages affect all line currents, under such scenario.

The proposed control algorithm gives adequate compensating current reference even for non-ideal voltage system. Consequently, this paper is primarily concerned with the development of APF performance under non-ideal or distorted mains voltage. This paper presents a new technique with instantaneous power theory (p-q theory) as a suitable method to the analysis of nonlinear three-phase systems and for the control of APF. Performance of the proposed scheme has been found feasible and excellent to that of the instantaneous reactive power algorithms under various non-ideal mains test scenarios.

1.4 OUTLINE OF THE THESIS

The report consists of an introductory chapter which briefs about power system harmonics, non-ideal source voltage and the conventional methods of mitigation. The other chapters are as follows.

Chapter 2 gives a detailed study about fundamentals of power quality, power harmonics. The various power quality problems and various harmonic presented rectifier circuit are discussed.

Chapter 3 presents the ACTIVE POWER FILTER types and operation of shunt active power filter was explained.

Chapter 4 is dedicated to the control algorithm and the estimation of reference current using the p-q theorem (Clarke transformation).

Chapter 5 shows the complete details of the simulation model developed. The details of individual blocks and the output waveform are given by using the MATLAB simulink.

Chapter 6 explains the hardware implementation using a PIC microcontroller. Details of individual components used and their images are included. The image results obtained before and after compensation are shown.

Chapter 7 Project conclusion, report is concluded discussing the future scope of the project using advanced techniques and the applications are also discussed..

CHAPTER 2

POWER QUALITY AND HARMONICS

POWER QUALITY AND HARMONICS

2.1 POWER QUALITY

The power quality (PQ) problems in power distribution systems are not new, but only recently the effects of these problems have gained public awareness. Advances in semiconductor device technology have fuelled a revolution in power electronics over the past decade, and there are indications that this trend will continue. However these power equipments which include adjustable-speed motor drives (ASDs), electronic power supplies, direct current (DC) motor drives, battery chargers, electronic ballasts are responsible for the rise in related PQ problems. These nonlinear loads are constructed by nonlinear devices, in which the current is not proportional to the applied voltage. In the case of a sinusoidal voltage when applied to a simple nonlinear resistor in which the voltage and current vary non-linearly, the voltage is perfectly sinusoidal, the resulting current is distorted.

Nonlinear loads appear to be prime sources of harmonic distortion in a power distribution system. Harmonic currents produced by nonlinear loads are injected back into power distribution systems through the point of common coupling (PCC). These harmonic currents can interact adversely with a wide range of power system equipment, most notably capacitors, transformers, and motors, causing additional losses, overheating and overloading.

There are set of conventional solutions to the harmonic distortion problems which have existed for a long time. The passive filtering is the simplest conventional solution to mitigate the harmonic distortion. Although simple, these conventional solutions that use passive elements do not always respond correctly to the dynamics of the power distribution systems. Some even tuned to bypass specific harmonic frequencies. However, the use of passive elements at high power level makes the filter heavy and bulky. Moreover, the passive filters are known to cause resonance, thus affecting the stability of the power distribution systems.

Remarkable progress in power electronics had spurred interest in active power filter (APF) for harmonic distortion mitigation. The basic principle of APF is to utilize power electronics technologies to produce currents components that cancel the harmonic currents from the nonlinear loads. Previously, majority of controllers developed for APF are based on analogue circuits. As a result, the APF is inherently subjected to signal drift. Digital controller using digital signal processor (DSP) or microprocessor is preferable, primarily due to its flexibility and immunity to noise signals. However it is known that using digital methods, the high order harmonics are not filtered effectively. This is due to the hardware limitation of sampling rate in real-time application. Moreover, the utilization of fast switching transistors (i.e. IGBT or MOSFET) in APF application causes switching frequency noise to appear in the compensated source current. This switching frequency noise requires additional filtering to prevent interference with other sensitive equipments.

2.2VOLTAGE POWER QUALITY PROBLEMS

The following are the power quality problems

- Voltage Sag
- Voltage Swell
- Voltage Interruption
- Under/ Over Voltage
- Voltage Flicker
- Harmonic Distortion

2.2.1 Voltage Sag

A voltage sag is a reduction in the RMS voltage in the range of 0.1 to 0.9 p.u. (retained) for duration greater than hall a mains cycle and less than 1 minute. Often referred to as a 'sag'. Caused by faults, increased load demand and transitional events such as large motor starting.

2.2.2 Voltage Swell

A voltage swell is an increase in the RMS voltage in the range of 1.1 to 1.8 p.u. for a duration greater than half a main cycle and less than 1 minute. Caused by system faults, load switching and capacitor switching.

2.2.3 Voltage Interruption

A *voltage interruption* is the complete loss of electric voltage. Interruptions can be short duration (lasting less than 2 minutes) or long duration. A disconnection of electricity causes an interruption—usually by the opening of a circuit breaker, line recloser, or fuse

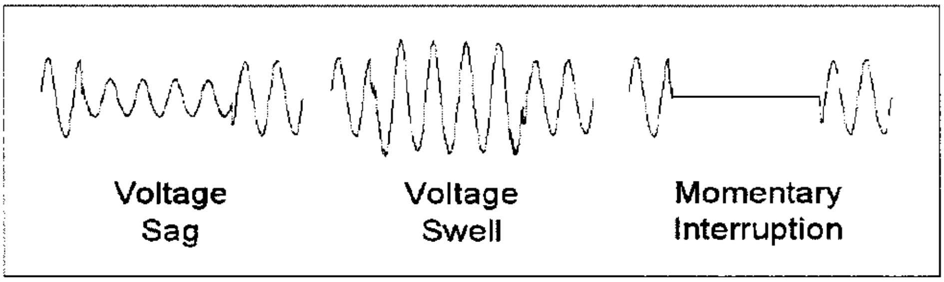

Figure 2.1 RMS Voltage during Voltage Sag, Swell, Momentary Interruption

2.2.4 Over Voltage and Under Voltage

- Long-duration voltage variations that are outside the normal limits (that is, too high or too low) are most often caused by unusual conditions on the power system. For example, out-of-service lines or transformers sometimes cause under voltage conditions. These types of root-mean-square (RMS) voltage variations are normally short term, lasting less than one or two days.
- In addition, voltage can be reduced intentionally in response to a shortage of electric supply.

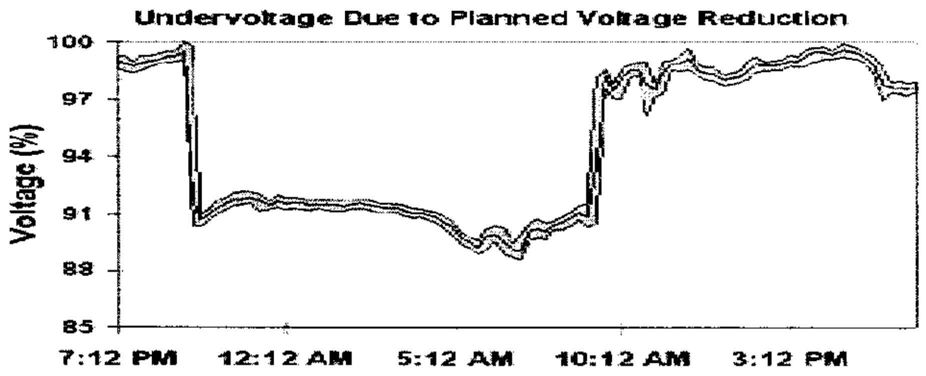

Figure 2.2 RMS Measurement Of Under Voltage during One Day

2.2.5 Voltage Flicker

- A waveform may exhibit *voltage flicker* if its waveform amplitude is modulated at frequencies less than 25 Hz, which the human eye can detect as a variation in the lamp intensity of a standard bulb.
- Voltage flicker is caused by an arcing condition on the power system.
- Flicker problems can be corrected with the installation of filters, static VAR systems, or distribution static compensators

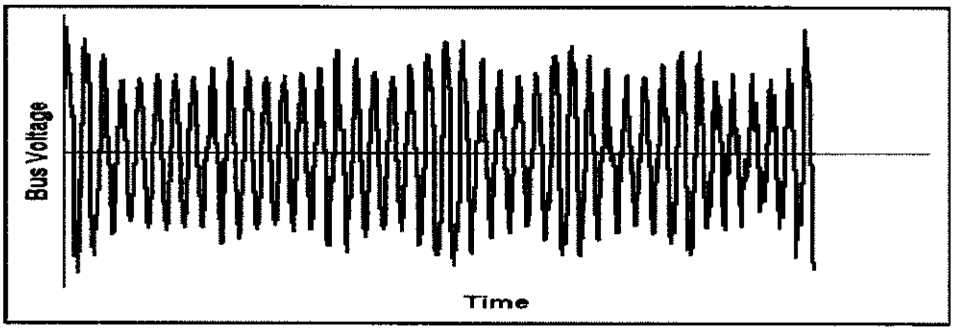

Figure 2.3 Voltage Waveforms Showing Flicker Created By an Arc Furnace

2.2.6 Harmonics Distortion

- Harmonics are periodic sinusoidal distortions of the supply voltage or load current caused by non-linear loads.
- Harmonics are measured in integer multiples of the fundamental supply frequency.
- In commercial facilities, computers, lighting, and electronic office equipment generate harmonic distortion. In industrial facilities, adjustable-speed drives and other power electronic loads can generate significant amounts of harmonics.
- Solutions to problems caused by harmonic distortion include installing active or passive filters at the load or bus, or taking advantage of transformer connections that enable cancellation of zero-sequence components.

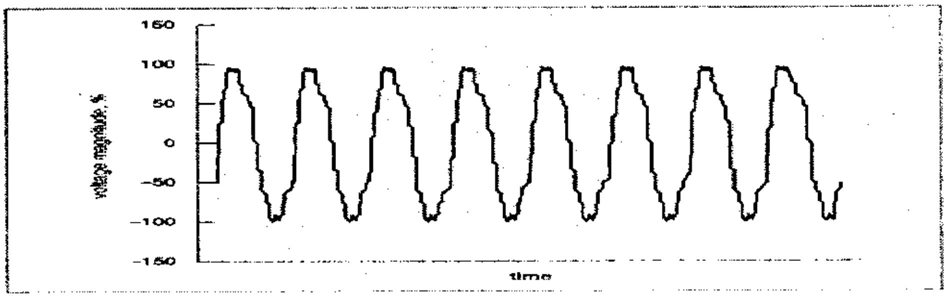

Figure 2.4 Distorted Voltage Waveforms

2.3 HARMONICS

- “A component frequency of a harmonic motion of an electromagnetic wave that is an integral multiple of the fundamental frequency”

Electrical generators try to produce electric power where the voltage waveform has only one frequency associated with it, the fundamental frequency. In the North America, this frequency is 60 Hz, or cycles per second. In European countries and other parts of the world, this frequency is usually 50 Hz. At 50 Hz, this means that fifty times a second, the voltage waveform increases to a maximum positive value, then decreases to zero, further decreasing to a maximum negative value, and then back to zero.

Our fundamental frequency is 50 Hertz

- 3rd Harmonic is 3 x 50Hz or *150Hz*
- 5th Harmonic is 5 x 50Hz or *250Hz*

Harmonics presents in the converter circuits in table 2.1

Type of device	Number of pulses	Harmonics present
half wave rectifier	1	2,3,4,5,6,7....
full wave rectifier	2	3,5,7,9,...
three phase, full wave	6	5,7, 11,13, 17,19,...
(2) three phase, full wave	12	11,13, 23,25, 35,37,...

Table 2.1 Harmonics Found In Different Converters

CHAPTER 3

ACTIVE POWER FILTER

ACTIVE POWER FILTER

3.1 INTRODUCTION

Active power filter has been proposed since 1970s. The advantages of the active filtering process over the passive one caused much research to be performed on active power filters for power conditioning and their practical applications. By implementing the active power filters for power conditioning; it provides functions such as reactive power compensations, harmonic compensations, harmonic isolation, harmonic damping, harmonic termination, negative-sequence current or voltage compensation and voltage regulation. The main purpose of the active power filter installation by individual consumers is to compensate current harmonics or current imbalance of their own harmonic-producing loads. Besides that, the purpose of the active power filter installation by the utilities is to compensate for voltage harmonics, voltage imbalance or provide harmonic damping factor to the power distribution systems.

Normally, active power filters can be classified into shunt and series one and both are designed to compensate for reactive power or harmonics. Active power filter consists of an inverter with switching control circuit. The inverter of the active power filter will generate the desired compensating harmonics based on the switching gates provided by the controller. The active power filter injects an equal-but-opposite distortion harmonics back into the power line and cancel with the original distorted harmonics on the line. Figure 3.1 shows the basic idea for the compensation principle of a shunt active power filter.

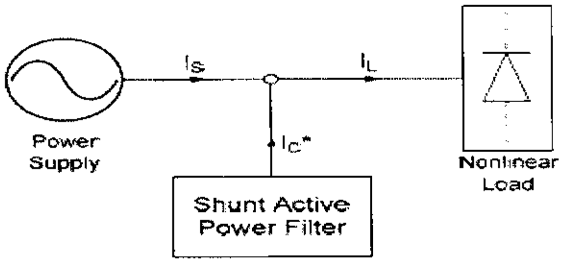

Figure 3.1 Basic Principle of Harmonic Currents Compensations

The harmonic current compensations by the active power filter are controlled in a closed loop manner. The active power filter will draw and inject the compensating current, I_C to the line based on the changes of the load in the power supply system. The supply line current, I_s is described by the following equation,

$$I_S=I_L+I_C$$

The line current, I_s is shaped to be sinusoidal by adding the compensating current, I_C into the distorted load current, I_L.

The problems of this active power filter are the suitable design for the controller and the filters configuration. Traditionally, its control techniques were mostly using pulse width modulation (PWM) technique. A control method using the instantaneous active-reactive power theorem complemented by using PWM control methods was proposed in the mid of 1970s. However, this proposed filter system was only suitable for the converters in motor drives or dc transmission which consist of emf vectors . Therefore, many researches have been carried out to find the best performed controller for the active power filter. However, before developing the controller, the configuration of the active power filter used in the design has to be defined.

3.2 CLASSIFICATIONS OF ACTIVE POWER FILTERS

Active power filters are divided into DC and AC filters. The DC filters are designed to compensate for current or voltage harmonics on the DC side of thyristor converters for HVDC systems and the DC link rectifier or inverter for traction systems. The AC filters are normally designed for the AC power system harmonic compensations. However, the active power filters is usually referred to the active ac power filters. There are various types of active power filters and these active power filters can be classified into different categories based on the system configuration, the power circuit, the control strategy and techniques.

3.2.1 Classification by System Configuration

The configurations of the active filters are the shunt, series or hybrid active-passive power filter. The shunt active filter shown in Figure 3.2 is the most fundamental system configurations. The shunt active power filter is controlled to draw and inject compensating current, Ic to the power system and cancel the harmonic currents on the AC side of a general purpose rectifier.

The shunt active power filter is normally used for the thyristor or diode rectifier with a DC link inductor. Besides that, it has the capability of damping harmonic resonance between an existing passive filter and the supply impedance.

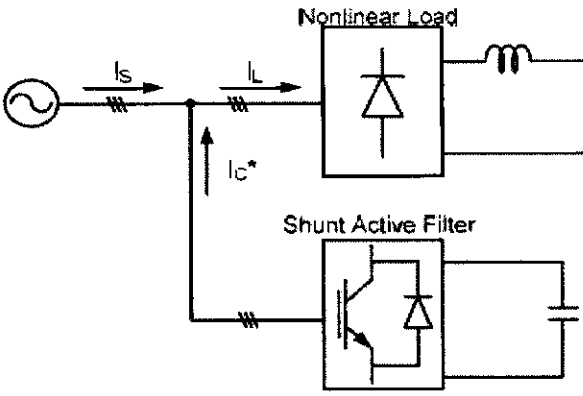

Figure 3.2 Shunt Active Power Filter

Figure 3.3 shows the system configuration of a used alone series active power filter. The series active power filter is connected in series with the utility by a matching transformer. Normally, the series active power filter is suitable for harmonic compensation of a voltage harmonic source such as diode rectifier with a DC link capacitor.

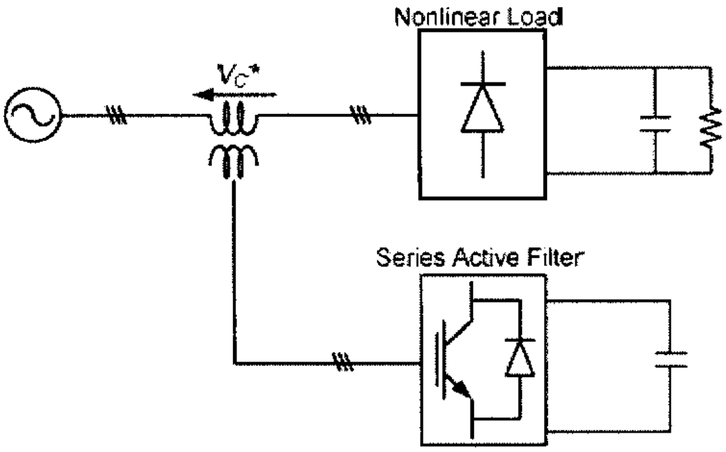

Figure 3.3 Series Active Power Filter

Both shunt and series active power filter carry different role for the harmonic compensation. The shunt and series active filters act as a current source with Ic and a voltage source with Vc respectively in order to compensate the harmonics currents or voltages occurred in the distorted line. In addition, the shunt active power filters also provide function such as compensates reactive power and the series active power filters can be used for ac voltage regulation. The shunt active power filters are now present in the commercial stage and the series active power filters are only used at laboratory level.

Another type of active filter configuration is the hybrid active-passive filters. The hybrid active-passive filter consists of the combination of the active and passive filter in order to perform better. The combination can be in different ways such as the combination of shunt active filter and shunt passive filter, or combination of series active filter and shunt passive filter, or combination of active filter connected in series with shunt passive filter and many more. Each of these combinations will have different performance, pros and cons. However, the combination of shunt active and shunt passive filter is more commercialized and more commonly used. The series active filter with shunt passive filter is usually used in testing field.

Protections for active power filter against over current are difficult if there is no reactive power control. As a result, hybrid filters are introduced. An example of a hybrid filter is the combination of a shunt active filter and a shunt passive filter that are connected in series. With the inclusion of the shunt passive filter, no harmonic current will flow through the active power filter. The passive filter in this case acts as a bypass to the harmonic current.

3.3 PROPOSED ACTIVE POWER FILTER

As the objective of this project is only to investigate and develop a current controller for an active power filter, a shunt active power filter configuration is chosen to compensate the current harmonics in a three phase power system. The shunt active power filter is represented by a voltage source inverter which is connected in parallel with a three phase nonlinear load.

3.4 SHUNT ACTIVE POWER FILTER OPERATION

The three-phase shunt active power filter is a three-phase **"current controlled voltage source inverter" (CC-VSI)** with a mid-point earthed, capacitor in the dc bus and inductors in the ac output .

Conventionally, a shunt APF is controlled in such a way as to inject harmonic and reactive compensation currents based on calculated reference currents. The injected currents are meant to "cancel" the harmonic and reactive currents drawn by the non-linear loads. However, the reference or desired current to be injected must be determined by extensive calculations with inherent delays, errors and slow transient response.

CHAPTER 4

CONTROL OF POWER FILTER

CONTROL OF POWER FILTER

4.1 BASIC PRINCIPLE

It is designed to be connected in parallel with the non-linear load to detect its harmonic and reactive current and then to inject a compensating current into the system. Therefore, the current drawn from the power system at the coupling point of the shunt APF will result in sinusoidal waveform. The source current (i_S) is the result of summing the load current (i_L) and the compensating current (i_C) as in -1

$$i_S = i_L + i_C \qquad (1)$$

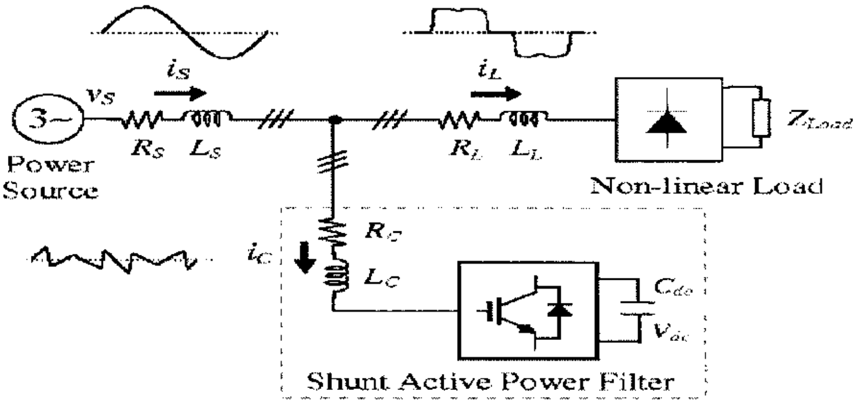

Figure 4.1 Basic Principle of The Three-Phase Shunt Apf

4.2 CLASSIFICATION BY CONTROL STRATEGY AND TECHNIQUES

The control strategy of the active power filters are divided into different groups according to the method applied in the harmonics extraction whether it is in frequency or time domain and also the harmonic detection methods.

There are two kinds of control strategies for harmonics extractions. One of the techniques is Fourier analysis in frequency domain and the other one is using instantaneous reactive-active power theory or called p-q theorem in time domain. The p-q theorem is basically a time domain analysis tool and it has been proven to be especially adequate as one of the active filters control strategies. However, in a stationary periodic process this p-q theorem can also be used in for a frequency domain analysis. This p-q technique promises instantaneous reactive extractions of the harmonics.

The harmonics detection methods are related to the domain used in the control strategy. In frequency domain, harmonics will be represented by the series Fourier equation. Analysis and calculations need to be done and in order to produce control switching to the active filter which is based on the derived Fourier equations. In time domain, three types of harmonics detections methods are proposed for the shunt active power filter. The methods are load current detection, supply current detection and voltage detection. The load and supply current detections are suitable for the shunt active filters installed in a region with one or more harmonic-producing loads by individual high-power consumers. The supply current detection method is the most basic harmonic detection method for the series active power filters by acting as a voltage source to each phase. The voltage detection is suitable for a shunt active power filter which acts as a shunt device of the unified power quality conditioner. This conditioner is suitable to be installed in primary distribution substations by utilities and also shunt active filters which are depressively installed on distribution systems by utilities

4.2.1 CONDITIONING METHODOLOGY IN TIME DOMAIN

For the time domain harmonic compensation, the harmonics correction is based on the principle of the p-q theorem mentioned before. Based on this theory, three correction techniques can be used in time domain. The techniques are the triangular wave method, hysteresis method and the deadbeat method. The easiest technique to be implemented is the triangular wave method. However, this technique can generate only a two-state switching function. Therefore, hysteresis method is proposed, where by, it can be implemented in both two and three-states switching function inverter. Hysteresis method is the most commonly proposed time domain correction technique. As for the deadbeat controlled based switching functions, it is less popular for implementation in active power filters. However, it has been proposed to be used in current control for a voltage source inverter with an adaptive hysteresis current control in year 2000 the time domain compensating techniques are simpler and have good dynamic response. Consequently, the time domain correction technique is used in this project.

4.3 INSTANTANEOUS ACTIVE AND REACTIVE THEORY

The development of the first prototype based on this instantaneous power theory for active power filter was in 1983 by Akagi and Nabae from Japan. This theorem has been study and extended into different approaches such as moving average p-q theory, extension p-q theory and single phase p-q theorem. In 2002, Aredes from Brazil had implemented this theory in control strategies for power line conditioners and active filters. For a three phase power system, the instantaneous reactive-active power theorem or p-q theorem is expressed as an instantaneous space vectors in voltage or current form.

This theory is based on time-domain, what makes it valid for operation in steady-state or transitory regime, as well as for generic voltage and current power system waveforms, allowing to control the active power filters in real-time. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation (exception done to the need of separating the mean and alternated values of the calculated power components).

The p-q theory performs a transformation known as "Clarke Transformation" of a stationary reference system of coordinates $a - b - c$ to a reference system of coordinates $\alpha - \beta - 0$, also stationary.

4.3.1 Clarke Transformation

It converts balanced three-phase quantities into balanced two-phase quadrature quantities. The transformation implements these equations

$$Id = Ia$$

$$Iq = (2Ib + Ia)/\sqrt{3}$$

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4.3.1 Clarke Transformation

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and is illustrated in the following figure.

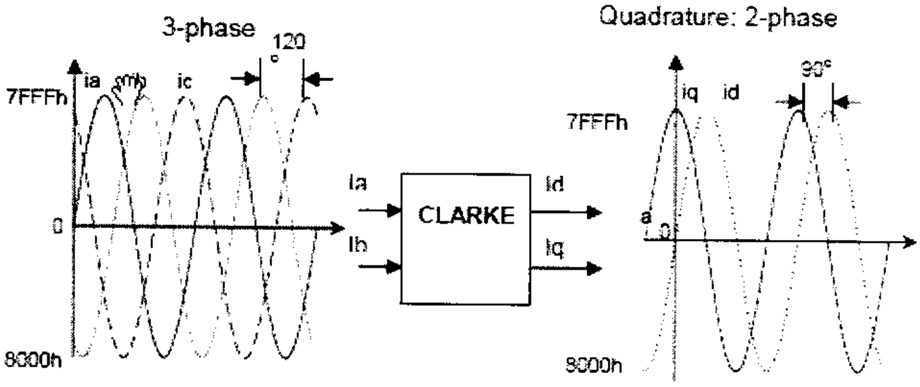
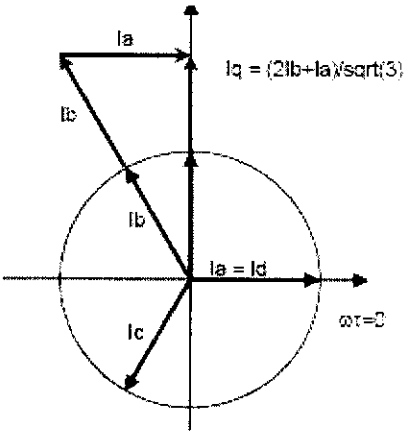


Figure 4.2 Clarke Transformation Phase Diagram

The inputs to this block are the phase a (`As`) and phase b (`Bs`) components of the balanced three-phase quantities and the outputs are the direct axis (`Alpha`) component and the quadrature axis (`Beta`) of the transformed signal.

The instantaneous outputs are defined by the following equations and are shown in the following figure:

$$ia = I * \sin(\omega t)$$
$$ib = I * \sin(\omega t + 2\pi/3)$$
$$ic = I * \sin(\omega t - 2\pi/3)$$
$$id = I * \sin(\omega t)$$
$$iq = I * \sin(\omega t + \pi/2)$$



The variables used in the preceding equations and figures correspond to the variables on the block as shown in the following table:

	Equation Variables	**Block Variables**
INPUT	ia	As
	ib	Bs
OUTPUT	id	alpha
	iq	beta

Table 4.1 Clarke Transformation

4.4 PROPOSED METHOD

In the proposed method, the number of required CSs is minimized as shown in Fig-4.3. Sensing only two phase source voltages and currents along with a dc-link voltage is adequate to compute reference currents of the three-phase shunt APF. In this way, the overall system design can be easily applied, and the total implementation cost is reduced. The waveform of the source current in the proposed control method can be approximated as a sinusoidal waveform after compensation.

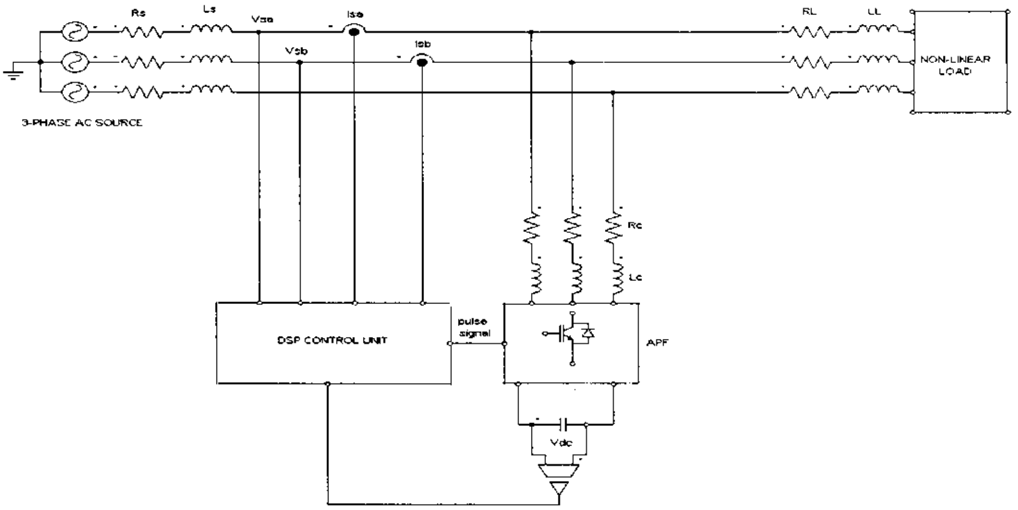


Figure 4.3 Proposed Shunt APF Configuration

It consists of p calculation including simplified Clarke Transformation, a low pass filter (LPF), one proportional- integral (PI) controller for dc voltage regulator, reference current calculation including simplified inverse Clarke Transformation and hysteresis - band current controller. It can be seen in Figure-4.4 that only source voltage and current signals are utilized in the control circuit of the proposed shunt APF to calculate the reference currents of the voltage source inverter (VSI). Thus, the proposed control method is simpler than that of the conventional APF algorithms. In this study, the shunt APF is connected to a three-phase three-wire system, which has balanced source voltages and loading conditions.

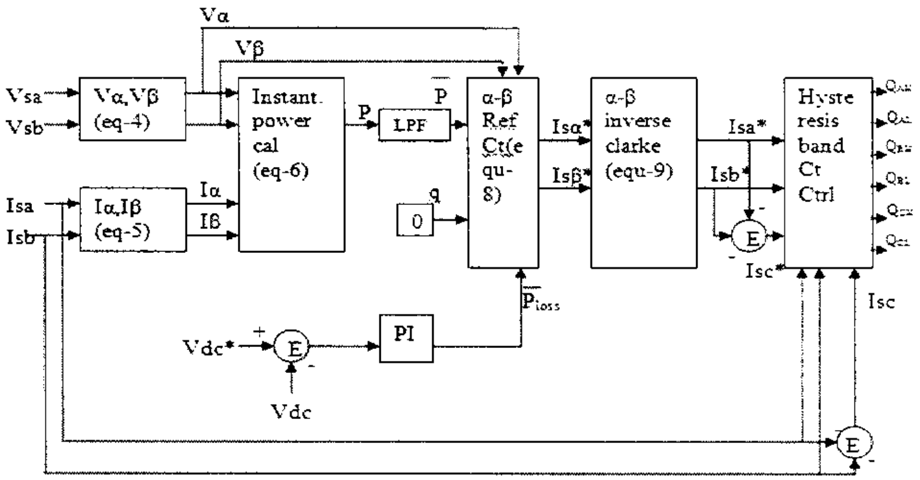


Figure 4.4 Block Diagram Simplified Control Method For The Three-Phase Shunt APF

Thus, the sums of both the instantaneous source voltages and currents of the three phases are zero. As a result, measuring only two source voltages and currents are adequate for the reference current calculations. Therefore, the conventional Clarke Transformation of the source voltages and currents are calculated as shown in (2) and (3)

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} \sqrt{3/2} & 0 \\ 1/\sqrt{2} & \sqrt{2} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \end{bmatrix} \qquad (2)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} \sqrt{3/2} & 0 \\ 1/\sqrt{2} & \sqrt{2} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \end{bmatrix} \qquad (3)$$

In this paper, in order to perform easily implementation of the α-β transformations in the (2) and (3) are multiplied with $\sqrt{2}/3$ and the simplified Clarke transformation are obtained as in (4)and (5).

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1/\sqrt{3} & 2/\sqrt{3} \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \end{bmatrix} \qquad (4)$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1/\sqrt{3} & 2/\sqrt{3} \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \end{bmatrix} \qquad (5)$$

In the conventional p-q theory based control algorithm with load current measurement, the instantaneous imaginary power (q) is calculated and its negative is used in the control technique for reactive power compensation. The calculation of the q is not required in the proposed method, since it is not desired to draw the q from the source for power factor correction. The calculation of the instantaneous real power (p) is adequate as shown in (6). The complicated

Calculations in the conventional instantaneous reactive power theory are not required in the proposed algorithm. Therefore, the proposed control scheme has been simplified in the calculations given below.

$$P = V_{sa}\, i_{sa} + V_\beta\, i_\beta \qquad (6)$$

The instantaneous real power includes ac and dc values, can be expressed as

$$P = P_{DC} + P_{AC} \qquad (7)$$

In the proposed control algorithm, instantaneous imaginary power is set to zero (q=0) in order to compensate reactive power. Therefore, a single dc component of the real power (P) is selected as a reference for harmonic and reactive power compensation. The compensation current references are calculated by (8). In order to produce the dc component of the instantaneous real power(P).it is filtered using 1st order LPF with a cut-off frequency at 50 Hz. The additional average real power (P_{loss}) is added to the dc component of the instantaneous real power (P) to cover the VSI losses of the shunt APF.

$$\begin{bmatrix} i_{s\alpha}* \\ i_{s\beta}* \end{bmatrix} = \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} P+P_{loss} \\ 0 \end{bmatrix} \begin{bmatrix} 1 \\ V^2_\alpha+V^2_\beta \end{bmatrix} \qquad (8)$$

In this study, the compensation current references in the α-β coordinates ($i^*_{s\alpha}\ i^*_{s\beta}$) are then transformed back into the a-b-c coordinates ($i^*_{sa}\ i^*_{sb}$) through the inverse simplified Clarke Transformation as given below.

$$\begin{bmatrix} i_{sa}* \\ i_{sb}* \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I_{c\alpha}* \\ I_{c\beta}* \end{bmatrix} \qquad (9)$$

The phase "C" current reference ($i*_{SC}$) is calculated by

$$i_{sc}* = -(i_{sa}*+i_{sb}*) \qquad (10)$$

These reference currents should be supplied to the power system by switching of the insulated-gate-bipolar-transistor (IGBT). The method for the generation of the switching pattern is achieved by the instantaneous current control of the shunt APF line currents. The actual source currents ($i_{Sa}\ i_{Sb}$) are measured instantaneously and actual phase ''C'' current (i_{sc})is obtained from Fig-4.4. Then they are compared with the reference currents (isa*,isb*,isc*) generated by the control algorithm in the hysteresis-band current controller. Three hysteresis-band current controllers generate the switching pattern of the VSI. The switching logic is formulated as below

- If $i_{Sa} < (i*_{sa} - HB)$ higher switch is OFF and lower switch is ON for leg "A" (QA=1)
- If $i_{Sa} > (i*_{sa} + HB)$ higher switch is ON and lower switch OFF for leg "A" (QA = 0).

there is no limit to the switching frequency. Additional circuitry on the other hand can be used to limit the maximum switching frequency.

The principle of the hysteresis control method for an active power filter is implemented by presetting the upper and lower tolerance limits which need to be compared to the extraction error signal. The maximum error is the difference between the upper and lower limit, and this hysteresis tolerance bandwidth is mostly equal to two times of the error. If the error signal is within the tolerance band, there will be no switching action for the filter. However, when the error leaves the tolerance band, switching pulses will be generated and the active power filter will produce signals to be injected back into the supply line.

Figure 4.5 illustrates the ramping of the current between the two limits where the upper hysteresis limit is the sum of the reference current and the maximum error or the difference between the upper limit and the reference current and for the lower hysteresis limit, it is the subtraction of the reference current and the minimum error. Supposing the value for the minimum and maximum error should be the same. As a result, the hysteresis bandwidth is equal to two times of error.

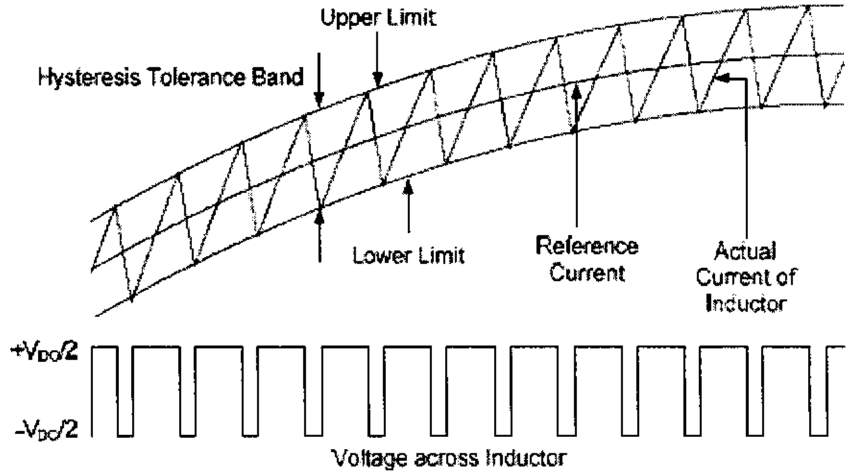


Figure 4.5 Hysteresis Current Control Operation Waveform

According to the operating principle of the inverter, the output voltages of each phase are significant to the switching pulses of the switches in each leg. As a result, the switching gates for the active power filter can be obtained. The voltage across the inductors show the frequency of the switching and the frequency can be altered by adjusting the width of the hysteresis tolerance band. Smaller inductance yields larger current difference and causes the slope of the saw tooth to increase.

CHAPTER 5

SIMULATION

SIMULATION

5.1 SIMULATION DIAGRAM

MATLAB is a software package for high performance numerical computation and visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. The name MATLAB stands for matrix laboratory. There are several optional toolboxes available from the developers of MATLAB. In the simulation circuit the R-L load is connect with a three phase source. Between the source and load at point of common coupling the IGBT inverter is connect as active power filter with control unit. The figure 5.1 shows the simulation circuit of proposed method.

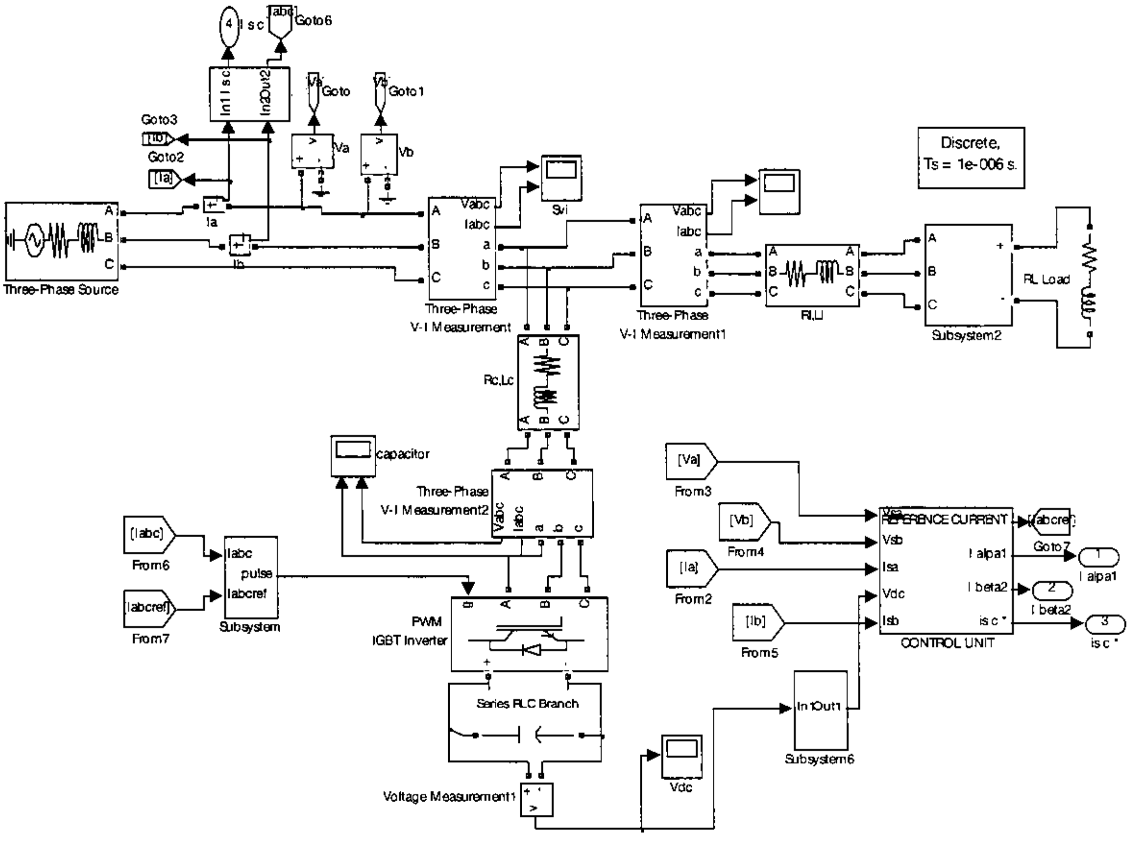


Figure 5.1 Simulation Diagram of Proposed Method

5.2 CONTROL BLOCK SIMULATION

From the source voltage and source current the Alpha, Beta and the Real (P) values are find. From that using equation (8), (9) to calculate the Reference current. . The figure 5.2 shows the simulation control circuit.

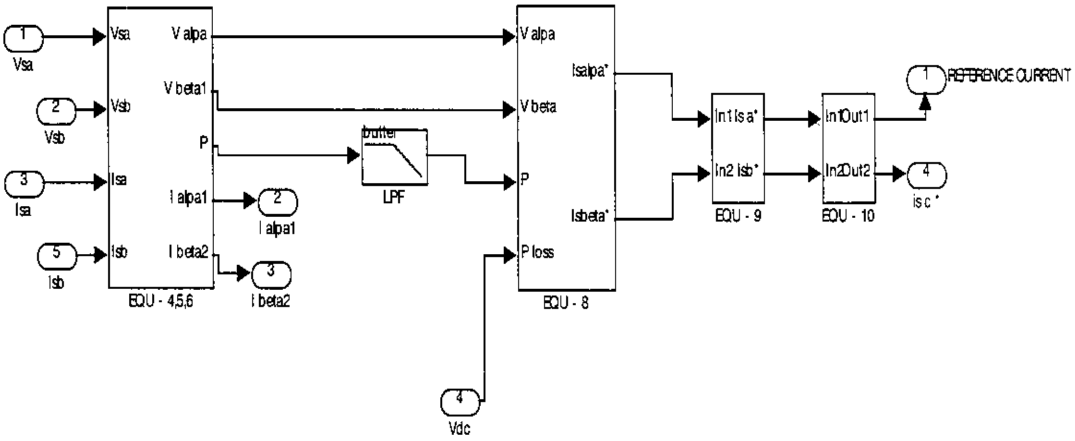


Figure 5.2 Simulation Diagram of Control Circuit

5.2.1 ALPHA (α), BETA (β) – CALCULATION

The subsystem of the equation (8) shown in the figure 5.3 for calculate the Alpha, Beta values.

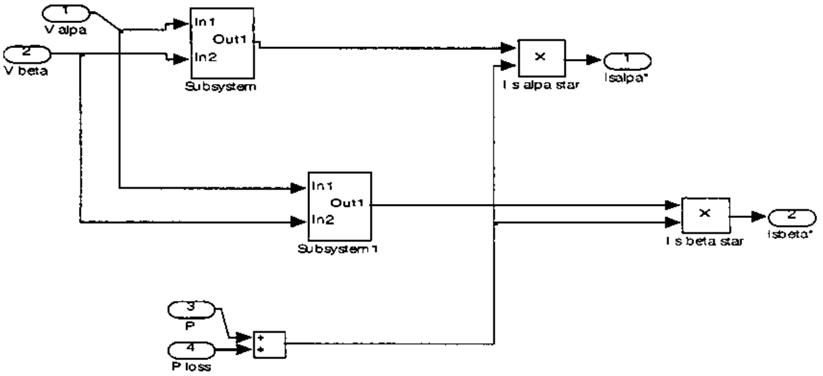


Figure 5.3 Simulation Diagram of α-β Calculation

5.2.2 Real Value (P) - CALCULATION

To calculate the real (P) power value subsystem shown in figure 5.4.by using the source voltage and source current the Alpha, Beta values are find from that value the real value is calculated.

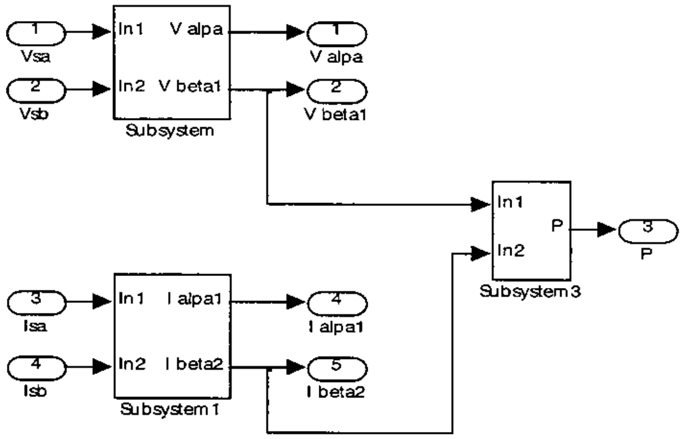


Figure 5.4 Simulation Diagram of Real Value (P) – Calculation

5.2.3 SUBSYSTEMS

The subsystem used in the simulation circuit to find the reference current of two phases is shown in figure 5.5.

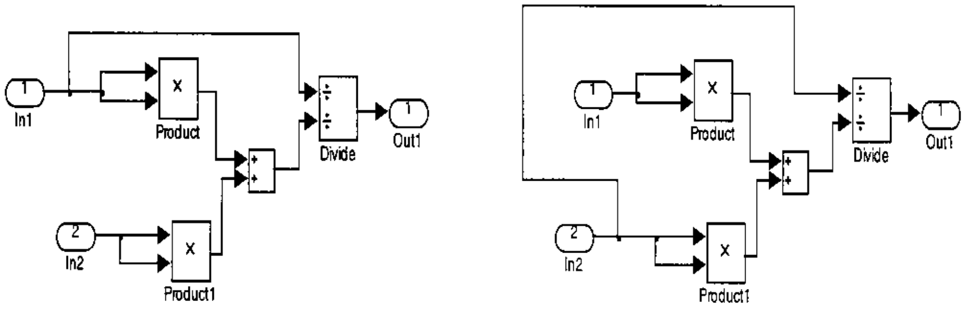


Figure 5.5 Simulation Diagrams of α-β Subsystems

5.3 SIMULATION OUTPUT

The simulation output of the proposed system are shown below. The source voltage, source current, load current, compensate current are named as fig 5.6,5.7,5.8,5.9.

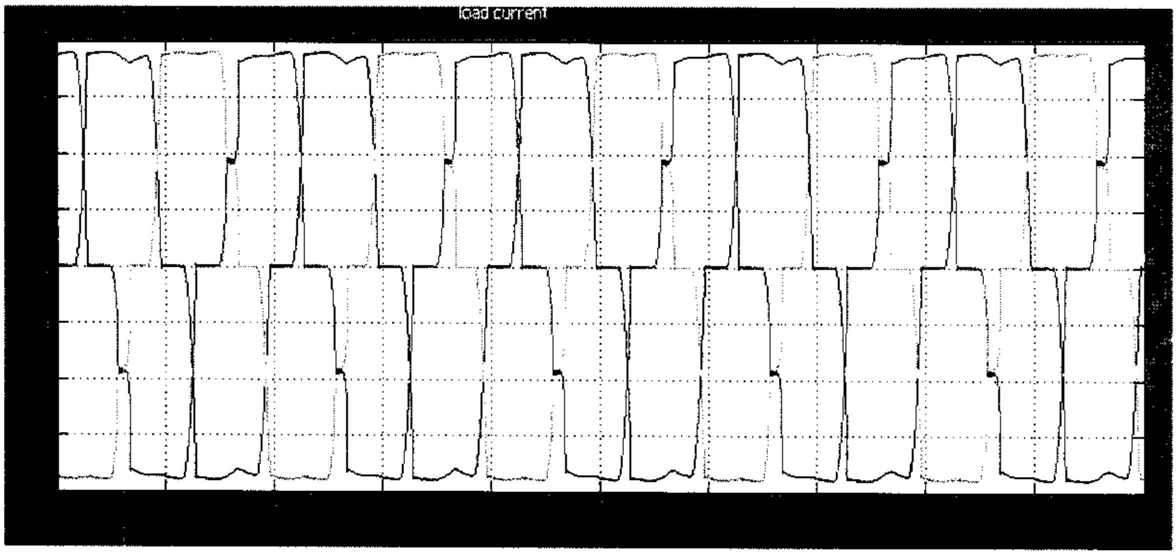


Figure 5.6 Load Current Waveform

Figure 5.7 Compensation Current Waveform

By adding the load current and the compensation current the source current get sinusoidal current waveform.

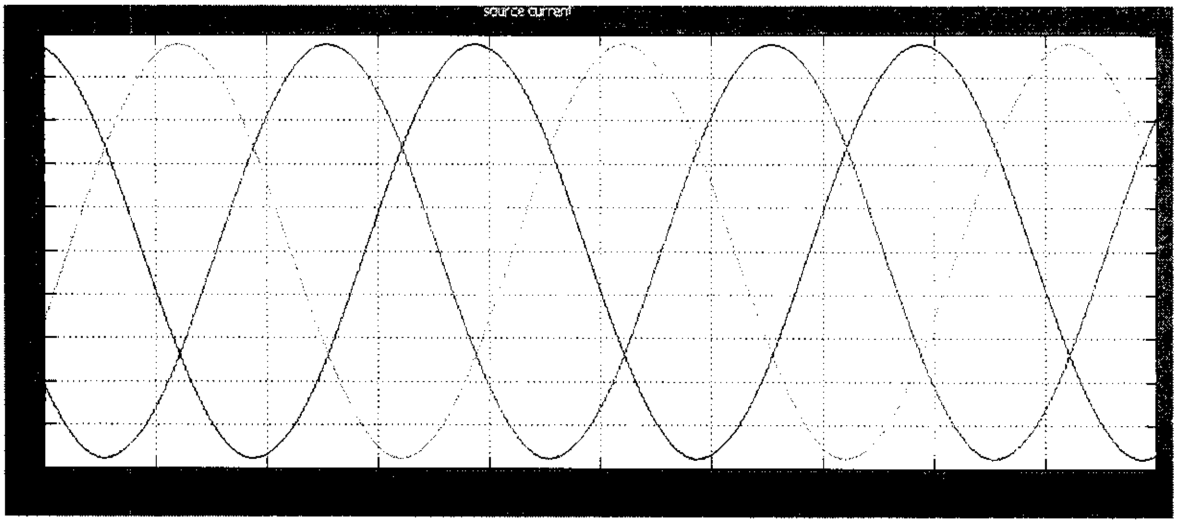


Figure 5.8 Source Current Waveform after Compensation

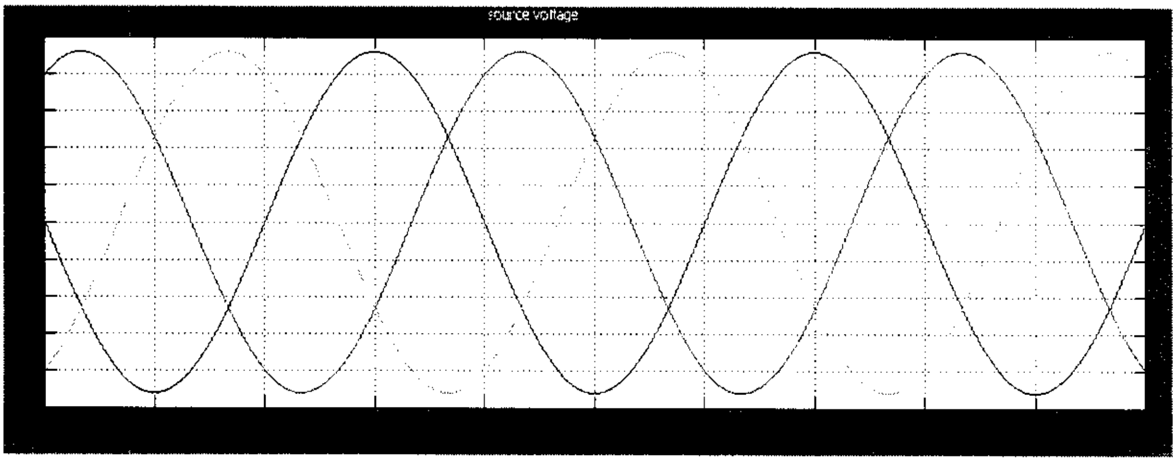


Figure 5.9 Source Voltage Waveform

The simulation diagram parameter are :

SYSTEM PARAMETER

- Source Voltage (Vsabc) = 220V Vrms
- System Frequency(fs) = 50 Hz

APF PARAMETER

- DC Link Voltage(Vdc) = 750V
- DC side capacitance (Cdc) = 1100 pF
- AC side inductance (Lc) = 3.75 mH

LOAD PARAMETER

- AC side inductance (Lc) = 1 mH
- DC side Resistance(RL dc) = 18 ohm
- DC side Inductance (L dc) = 85mH

For this parameter values the THD value for the before compensation is 22.34% .by using APF compensate current the after compensation the THD value is reduced to below 5%.

Therefore source current with reduced distortions are obtained and the Current THD reduced to is 3.49%. The following figure represents the source current THD with the presence of Active Power filter.

5.4 THD VALUE OF SIMULATION RESULTS

It is clearly represent the with filter and without filter conditions and the APF compensates harmonic currents into the line there for making the input supply is sinusoidal. The improvisation of power quality is given below as THD improvement.

Source current THD in % (Without filter)	Source current THD in % (With filter)
22.34	3.49

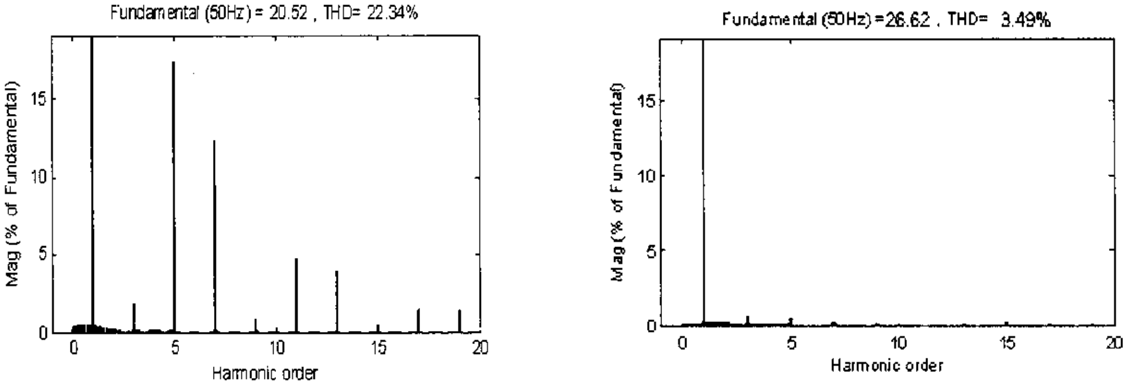


Figure 5.10 THD Value for Before Compensation and after compensation

CHAPTER 6

HARDWARE IMPLEMENTATION AND RESULTS

HARDWARE IMPLEMENTATION AND RESULTS

6.1 INTRODUCTION

A prototype of the project is developed using a PIC microcontroller as the control circuit and a MOSFET bridge as the VSI inverter. An H-bridge inverter with four IRF250 MOSFET's is constructed which is then coupled to the main system using a coupling transformer. The inverter circuit obtains the command from the microcontroller. A potentiometer is used to bring changes in the source current and to which the controller code activates the gating pulses to the inverters.

6.2 HARDWARE SETUP

The hardware consists of three main portions. The power supply and load section, the microcontroller and the VSI inverter bridge with DC capacitor. Three separate power supply circuits are being used in this project. A 230V/50 Hz power supply is stepped down to 9V by a step down transformer.This stepped down supply is fed to the diode bridge rectifier through a 63V/2200mfd capacitor in parallel which acts as a smoothing filter. A 1 ohm /5V resistor is fixed in series with the rectifier across which the CRO is connected to view the waveform. A 230VAC supply is stepped down to a 5V and 15V by step down transformers to supply the isolation circuits. These supplies are regulated by the IC voltage regulators. The VSI Bridge is supplied from a step supply across a 1000mfd capacitor which derives its energy from the stepped down supply.

The microcontroller senses the input current through the port RA0 in pin2 which acts an ADC in this project. The driving commands to the VSI bridge inverter is fired through the ports RB4, RB5, RB6, and RB7 through an opto-isolator circuit. The VSI bridge inverter converts the input dc to the compensating waveform as commanded by the microcontroller. VSI Bridge is injected into the source –load system through a coupling transformer with 1:1 ratio.

6.3 WORKING

The RL load connected in the setup acts as the source of harmonics. The harmonics produced due to this load is shown below in the picture. The supply is 9V AC. The current is sensed through a potentiometer which is adjusted to bring the compensation. The microcontroller performs the algorithm to generate the PWM driving pulses for the H-bridge MOSFET. These signals are isolated and amplified through the opto-isolators provided for each MOSFET device. The opto-coupler devices are given with separate supply for functioning .

The inverter is supplied with DC supply of 12V through a bridge rectifier. The inverter produces compensating waveforms as commanded by the controller. This compensating current is fed to the line through a transformer.

As the load varies the distortion or the waveform shape varies accordingly. This project is designed for a particular load of bridge rectifier supplying an RL load. To view the results for various values of the resistance / inductance a reset circuit of the controller is used each time for the corresponding compensation waveform.

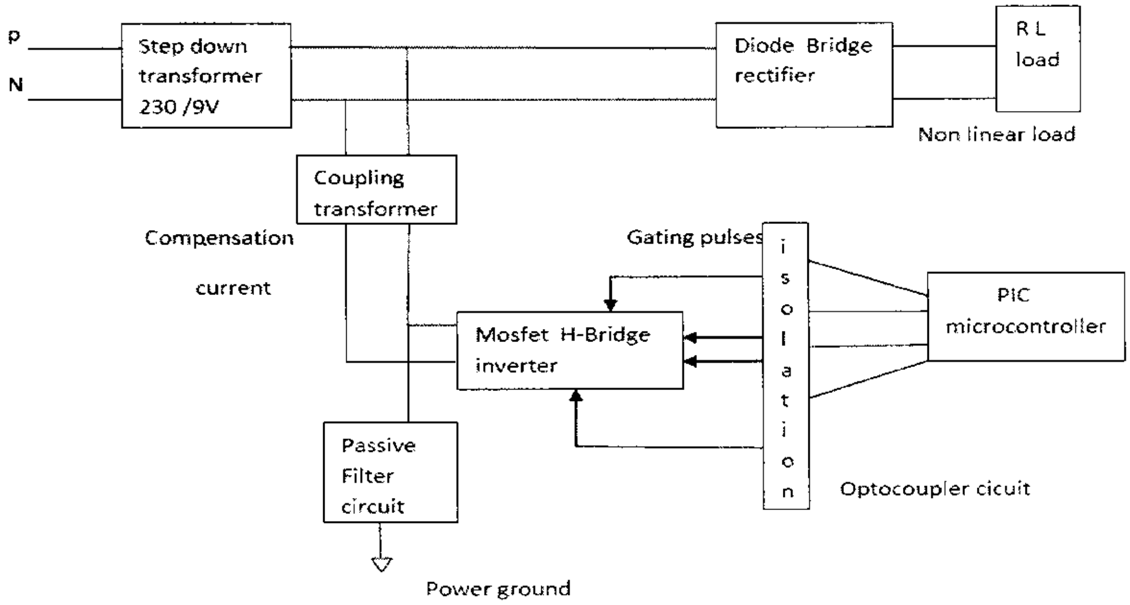


Figure 6.1 Block Diagram of the Prototype Develop

Figure 6.2 The hardware setup with a RL load

6.4 WAVEFORM RESULTS

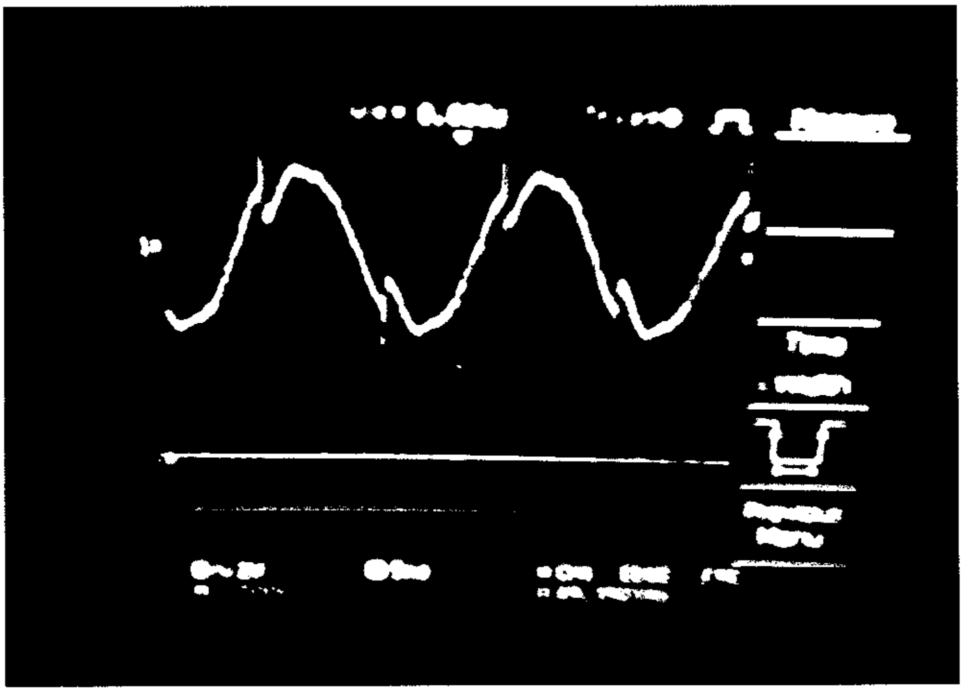


Figure 6.3 Waveform of Source Current With R-L Load

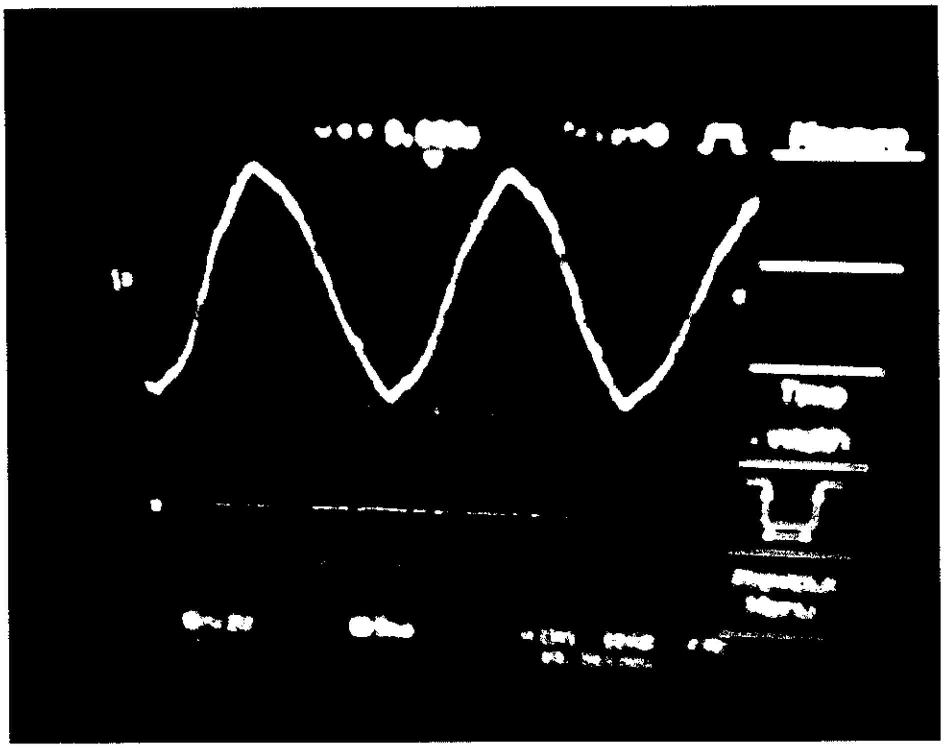


Figure 6.4waveform with Same Setup After Filtering

6.5 DESCRIPTION OF THE COMPONENTS

6.5.1 POWER SUPPLY

The ac voltage, typically 220V rms, is connected to a transformer, which steps that ac voltage down to the level of the desired dc output. A diode rectifier then provides a full-wave rectified voltage that is initially filtered by a simple capacitor filter to produce a dc voltage. This resulting dc voltage usually has some ripple or ac voltage variation.

A regulator circuit removes the ripples and also remains the same dc value even if the input dc voltage varies, or the load connected to the output dc voltage changes. This voltage regulation is usually obtained using one of the popular voltage regulator IC units.

THREE-TERMINAL VOLTAGE REGULATORS

Figure shows the basic connection of a three-terminal voltage regulator IC to a load. The fixed voltage regulator has an unregulated dc input voltage, Vi, applied to one input terminal, a regulated output dc voltage, Vo, from a second terminal, with the third terminal connected to ground. For a selected regulator, IC device specifications list a voltage range over which the input voltage can vary to maintain a regulated output voltage over a range of load current. The specifications also list the amount of output voltage change resulting from a change in load current (load regulation) or in input voltage (line regulation).

FIXED POSITIVE VOLTAGE REGULATORS

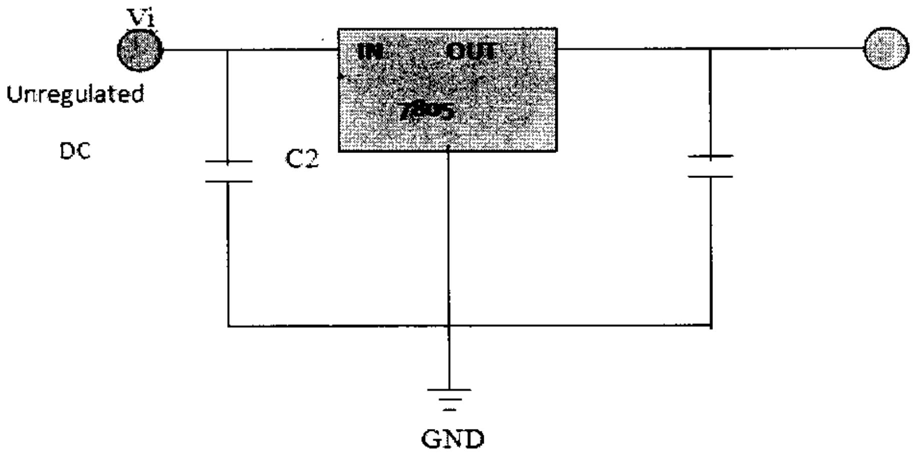


Figure 6.5 Voltage Regulator IC

The series 78 regulators provide fixed regulated voltages from 5 to 24 V. Figure shows how one such IC, a 7812, is connected to provide voltage regulation with output from this unit of +12V dc. An unregulated input voltage Vi is filtered by capacitor C1 and connected to the IC's IN terminal. The IC's OUT terminal provides a regulated + 12V which is filtered by capacitor C2 (mostly for any high-frequency noise). The third IC terminal is connected to ground (GND). While the input voltage may vary over some permissible voltage range, and the output load may vary over some acceptable range, the output voltage remains constant within specified voltage variation limits. These limitations are spelled out in the manufacturer's specification sheets. A table of positive voltage regulated ICs is provided in table below.

IC Part	Output Voltage (V)	Minimum Vi (V)
7805	+5	7.3
7806	+6	8.3
7808	+8	10.5
7810	+10	12.5
7812	+12	14.6
7815	+15	17.7
7818	+18	21.0
7824	+24	27.1

Table 6.1 Positive Voltage Regulated ICs

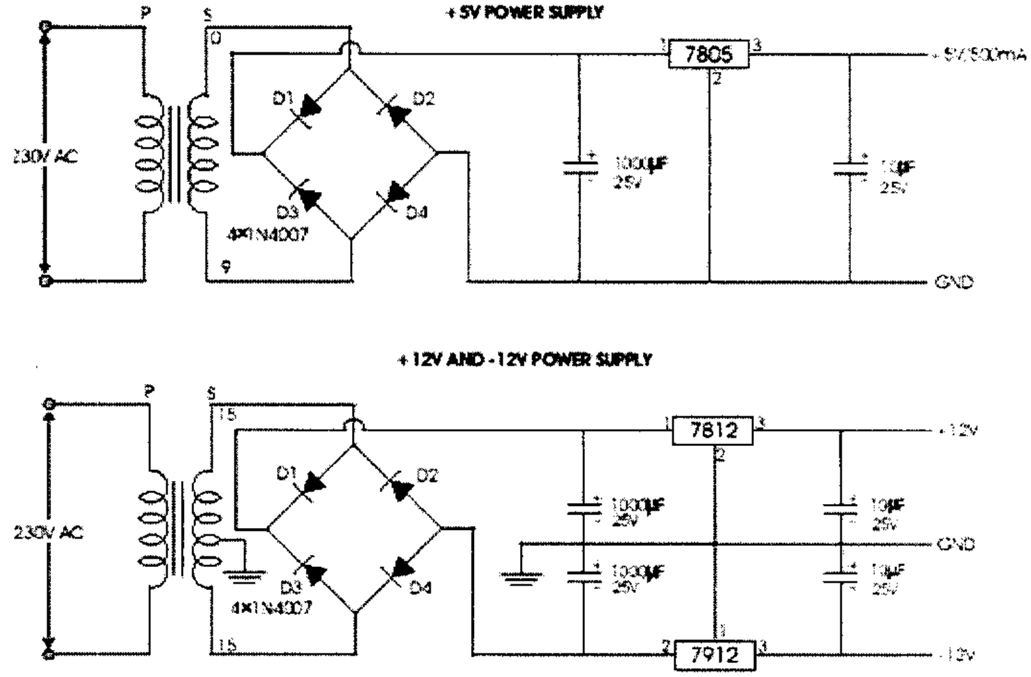


Figure 6.6 Power supply circuit diagram

6.5.2 H-BRIDGE INVERTER

The bridge inverter circuit is constructed using MOSFET devices. They are isolated from the control circuit using opto-couplers which protects the damage of any control devices.

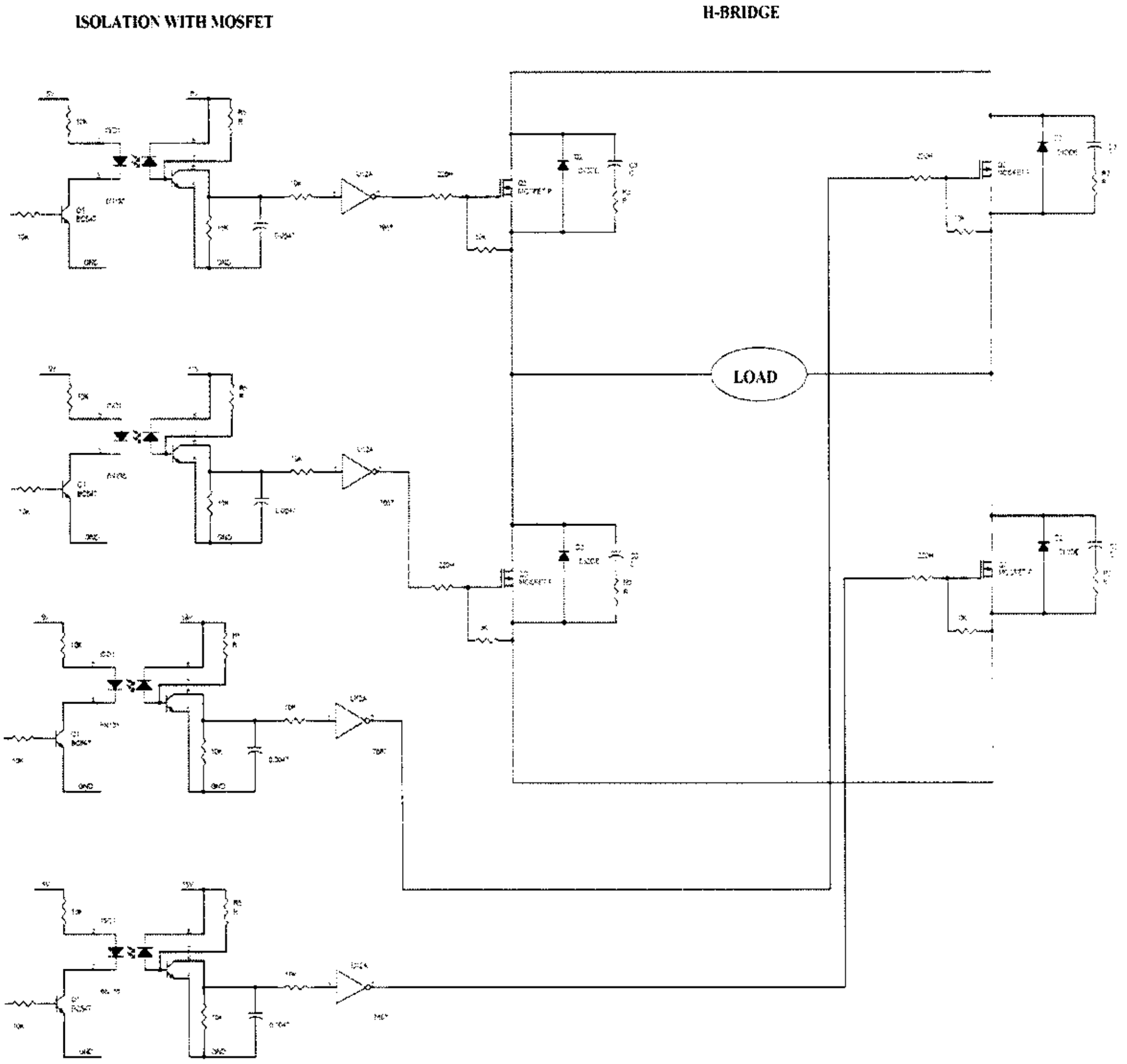


Figure 6.7 H-Bridge Inverter Circuit

CIRCUIT WORKING DESCRIPTION

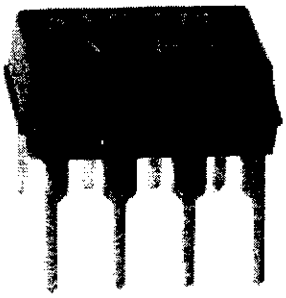
The isolation circuit is mainly used to isolate the high voltage and low voltage circuit, SCR and Triac circuit, mechanical relay and pulse transformer. Here the isolation circuit is constructed by the 6N135 opto coupler. The opto coupler consists of photo LED and photo transistor. The photo transistor conducting only when light rays falls on the base of the transistor. The signal to be isolated is given to base of BC547 switching transistor.

Whenever the signal is high, the transistor is switched ON, so the emitter and collector terminals are shorted. Now the photo LED is conducting and light rays falls on the photo transistor. Due to that the photo transistor is conducting and shorts the emitter and collector terminal. The 7667 inverter is connected in the collector terminal. So the ground signal that is zero signals is given to inverter input and high pulse is taken from the inverter output. Now the output pulse is equal to input pulse as applied to the base of the transistor BC547 (Q1).

OPTOCOUPLER

In electronics, an opto-isolator (or optical isolator, optocoupler, photocoupler, or photoMOS) is a device that uses a short optical transmission path to transfer a signal between elements of a circuit, typically a transmitter and a receiver, while keeping them electrically isolated — since the signal goes from an electrical signal to an optical signal back to an electrical signal, electrical contact along the path is broken. A common implementation involves a LED and a phototransistor, separated so that light may travel across a barrier but electrical current may not. When an electrical signal is applied to the input of the opto-isolator, its LED lights, its light sensor then activates, and a corresponding electrical signal is generated at the output. Unlike a transformer, the opto-isolator allows for DC coupling and generally provides significant protection from serious overvoltage conditions in one circuit affecting the other.

With a photodiode as the detector, the output current is proportional to the amount of incident light supplied by the emitter. The diode can be used in a photovoltaic mode or a photoconductive mode. In photovoltaic mode, the diode acts like a current source in parallel with a forward-biased diode. The output current and voltage are dependent on the load impedance and light intensity.



In photoconductive mode, the diode is connected to a supply voltage, and the magnitude of the current conducted is directly proportional to the intensity of light. An opto-isolator can also be constructed using a small incandescent lamp in place of the LED; such a device, because the lamp has a much slower response time than an LED, will filter out noise or half-wave power in the input signal. In so doing, it will also filter out any audio- or higher-frequency signals in the input. It has the further disadvantage, of course, (an overwhelming disadvantage in most applications) that incandescent lamps have relatively short life spans. Thus, such an unconventional device is of extremely limited usefulness, suitable only for applications such as science projects.

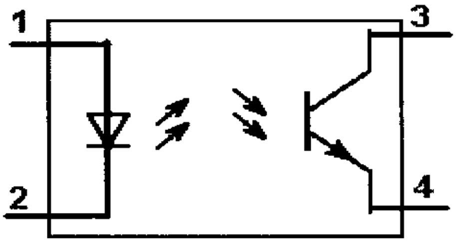


Figure 6.8 Optocoupler

The optical path may be air or a dielectric waveguide. The transmitting and receiving elements of an optical isolator may be contained within a single compact module, for mounting, for example, on a circuit board; in this case, the module is often called an optoisolator or opto-isolator. The photosensor may be a photocell, phototransistor, or an optically triggered SCR or Triac. Occasionally, this device will in turn operate a power relay or contactor. They are used to isolate low-current control or signal circuitry from transients generated or transmitted by power supply and high-current control circuits. The latter are used within motor and machine control function blocks.

MOSFET

The metal–oxide–semiconductor field-effect transistor (MOSFET, MOS-FET, or MOS FET) is by far the most common field-effect transistor in both digital and analog circuits. The MOSFET is composed of a channel of n-type or p-type semiconductor material (see article on semiconductor devices), and is accordingly called an NMOSFET or a PMOSFET (also commonly NMOSFET, PMOSFET).

The 'metal' in the name is now often a misnomer because the previously metal gate material is now a layer of polysilicon (polycrystalline silicon; why polysilicon is used will be explained below). Previously aluminium was used as the gate material until the 1980s when polysilicon became dominant, owing to its capability to form self-aligned gates.

To overcome power consumption increase due to gate current leakage, high-κ dielectric is replacing silicon dioxide as the gate insulator, and metal gates are making a comeback by replacing polysilicon .

Figure 6.9 MOSFET IRF250

IGFET is a related, more general term meaning insulated-gate field-effect transistor, and is almost synonymous with MOSFET, though it can refer to FETs with a gate insulator that is not oxide. Some prefer to use "IGFET" when referring to devices with polysilicon gates, but most still call them MOSFETs.

Usually the semiconductor of choice is silicon, but some chip manufacturers, most notably IBM, have begun to use a mixture of silicon and germanium (SiGe) in MOSFET channels. Unfortunately, many semiconductors with better electrical properties than silicon, such as gallium arsenide, do not form good semiconductor-to-insulator interfaces and thus are not suitable for MOSFETs. However there continues to be research on how to create insulators with acceptable electrical characteristics on other semiconductor material.

The gate is separated from the channel by a thin insulating layer of what was traditionally silicon dioxide, but more advanced technologies used silicon oxynitride. Some companies have started to introduce a high-κ dielectric + metal gate combination in the 45 nanometer node.

When a voltage is applied between the gate and source terminals, the electric field generated penetrates through the oxide and creates a so-called "inversion layer" or channel at the semiconductor-insulator interface. The inversion channel is of the same type – P-type or N-type – as the source and drain, so it provides a conduit through which current can pass. Varying the voltage between the gate and body modulates the conductivity of this layer and makes it possible to control the current flow between drain and source.

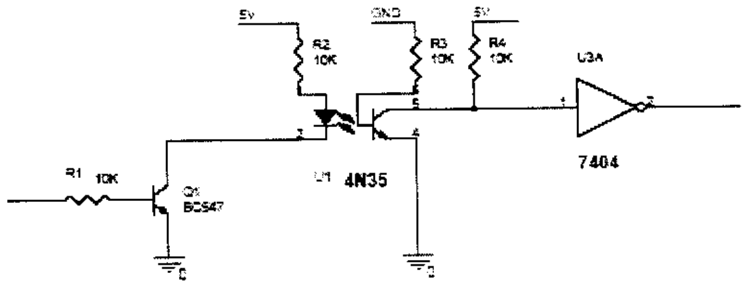


Figure 6.10 Opto Coupler with isolation

6.6 MICROCONTROLLER

The microcontroller that has been used for this project is from PIC series. PIC microcontroller is the first RISC based microcontroller fabricated in CMOS (complimentary metal oxide semiconductor) that uses separate bus for instruction and data allowing simultaneous access of program and data memory.

The main advantage of CMOS and RISC combination is low power consumption resulting in a very small chip size with a small pin count. The main advantage of CMOS is that it has immunity to noise than other fabrication techniques.

PIC (16F877)

Various microcontrollers offer different kinds of memories. EEPROM, EPROM, FLASH etc. are some of the memories of which FLASH is the most recently developed. Technology that is used in pic16F877 is flash technology, so that data is retained even when the power is switched off. Easy Programming and Erasing are other features of PIC 16F877.

SPECIAL FEATURES OF PIC MICROCONTROLLER

CORE FEATURES

- High-performance RISC CPU
- Only 35 single word instructions to learn
- All single cycle instructions except for program branches which are two cycle
- Operating speed: DC - 20 MHz clock input

  DC - 200 ns instruction cycle
- Up to 8K x 14 words of Flash Program Memory,

  Up to 368 x 8 bytes of Data Memory (RAM)

  Up to 256 x 8 bytes of EEPROM data memory
- Pin out compatible to the PIC16C73/74/76/77
- Interrupt capability (up to 14 internal/external
- Eight level deep hardware stack
- Direct, indirect, and relative addressing modes

- Power-on Reset (POR)
- Power-up Timer (PWRT) and Oscillator Start-up Timer (OST)
- Watchdog Timer (WDT) with its own on-chip RC Oscillator for reliable operation
- Programmable code-protection
- Power saving SLEEP mode
- Selectable oscillator options
- Low-power, high-speed CMOS EPROM/EEPROM technology
- Fully static design
- In-Circuit Serial Programming (ICSP) via two pins
- Only single 5V source needed for programming capability
- In-Circuit Debugging via two pins
- Processor read/write access to program memory
- Wide operating voltage range: 2.5V to 5.5V
- High Sink/Source Current: 25 mA
- Commercial and Industrial temperature ranges
- Low-power consumption:
    - < 2mA typical @ 5V, 4 MHz
    - 20mA typical @ 3V, 32 kHz
    - < 1mA typical standby current

PERIPHERAL FEATURES

- Timer0: 8-bit timer/counter with 8-bit prescaler
- Timer1: 16-bit timer/counter with prescaler, can be incremented during sleep via external crystal/clock
- Timer2: 8-bit timer/counter with 8-bit period register, prescaler and postscaler
- Two Capture, Compare, PWM modules

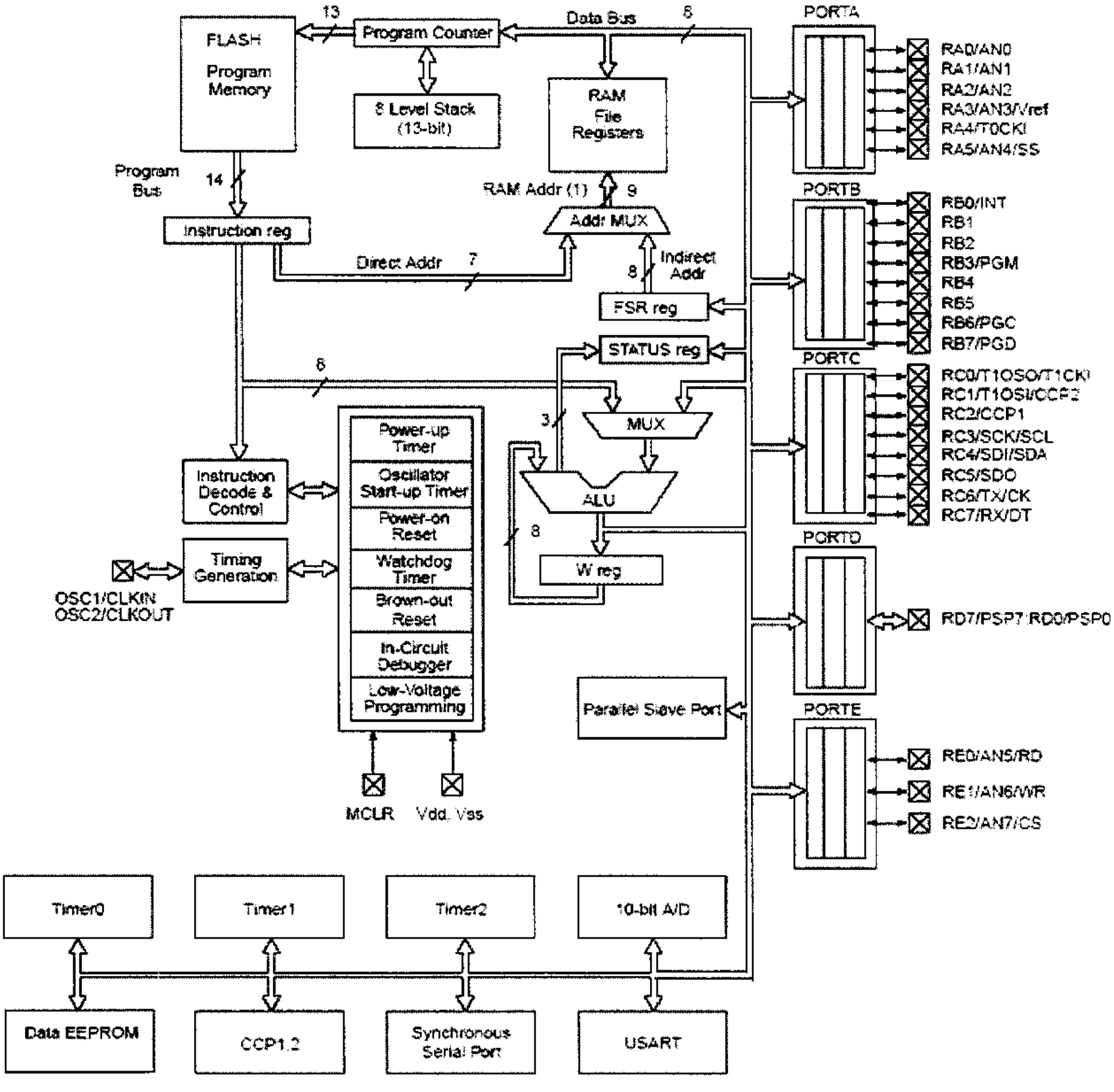
  Capture is 16-bit, max resolution is 12.5 ns,

  Compare is 16-bit, max resolution is 200 ns,

  PWM max. resolution is 10-bit
- 10-bit multi-channel Analog-to-Digital converter
- Synchronous Serial Port (SSP) with SPI. (Master Mode) and I2C. (Master/Slave)
- Universal Synchronous Asynchronous Receiver Transmitter (USART/SCI) with 9- bit address detection.

6.6.1 ARCHITECTURE OF PIC 16F877A

The complete architecture of PIC 16F877A is shown in the Figure 2.1. Table 2.1 gives details about the specifications of PIC 16F877A. Figure 2.2 shows the complete pin diagram of the IC PIC 16F877A.



Note 1: Higher order bits are from the STATUS register.

Figure 6.11 Architecture of PIC 16F877A

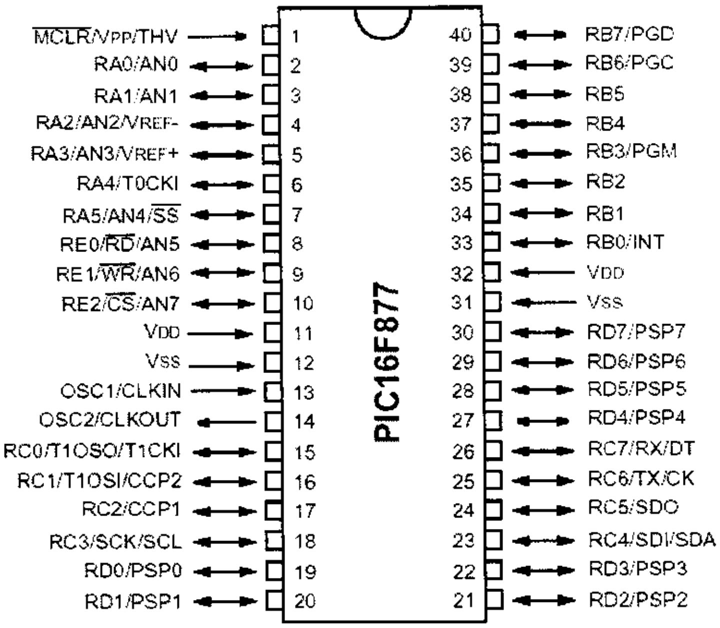


Figure 6.12 Pin diagram of PIC 16F877A

I/O PORTS

Some pins for these I/O ports are multiplexed with an alternate function for the peripheral features on the device. In general, when a peripheral is enabled, that pin may not be used as a general purpose I/O pin.

MEMORY ORGANISATION

There are three memory blocks in each of the PIC16F877 MUC's. The program memory and Data Memory have separate buses so that concurrent access can occur.

PROGRAM MEMORY ORGANISATION

The PIC16f877 devices have a 13-bit program counter capable of addressing 8K *14 words of FLASH program memory. Accessing a location above the physically implemented address will cause a wraparound.

The RESET vector is at 0000h and the interrupt vector is at 0004h.

DATA MEMORY ORGANISTION

The data memory is partitioned into multiple banks which contain the General Purpose Registers and the special functions Registers. Bits RP1 (STATUS<6) and RP0 (STATUS<5>) are the bank selected bits.

RP1:RP0	Banks
00	0
01	1
10	2
11	3

Each bank extends up to 7Fh (1238 bytes). The lower locations of each bank are reserved for the Special Function Registers. Above the Special Function Registers are General Purpose Registers, implemented as static RAM. All implemented banks contain special function registers. Some frequently used special function registers from one bank may be mirrored in another bank for code reduction and quicker access.

ANALOG TO DIGITAL CONVERTER (ADC)

There are two types of analog to digital converter is present in this IC. We use 10-bit ADC. The ADC module can have up to eight analog inputs for a device. The analog input charges a sample and hold capacitor. The output of sample and hold capacitor is the input into the converter. The converter then generates a digital result of this analog level via successive approximation. The A/D conversion of the analog input signal results in a Corresponding 10-bit digital number. The A/D module has high and low voltage reference input that is software selectable to some combination of VDD, VSS, and RA2 Or RA3.The A/D module has four registers. These registers are

A/D result high register (ADRESH)
A/D RESULT LOW REGISTER (ADRESL)
A/D CONTROL REGISTER 0 (ADCON0)
A/D CONTROL REGISTER 1 (ADCON1)

CHAPTER 7

CONCLUSION

CONCLUSION

7.1 POWER QUALITY IMPROVEMENT

The current harmonics in the power utility systems cause various quality problems like low power factor, overheating of electrical equipments, reduction in efficiency, false tripping of CB without fault currents. This project is successfully implemented by compensating for the harmonics present in the current waveform and bringing current in phase with the voltage thus rectifying the effect of harmonics on source side.

In this work an APF control scheme based on IRP theory has been proposed to improve the quality of the source current. It required minimized computations and parameters measurements. The simulation results with MATLAB-SIMULINK show the effectiveness of the algorithm within IEEE Limit.

A prototype is then developed using a PIC microcontroller and an H-Bridge MOSFET inverter acting as the shunt filter. Injection of compensation current is done through a coupling transformer into the supply–load system and the waveforms obtained on a Digital CRO.

7.2 FUTURE SCOPE

The future scope of the project involves the implementation of the p-q theory algorithm using advanced and sophisticated digital controllers like Digital Signal Processors. Digital Signal Processors are well suited for this implementation with their high sampling and processing speeds and better immunity to external interferences. Still researches are made on DSP implementation to bring better results than existing and mainly to figure out a cost effective method. More advanced techniques using Artificial Neural Networks and Wavelet technologies are still under research. These methods prove to bring far better results in near future.

APPENDIX

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APPENDIX

A.1 HARMONIC LIMITATION

IEEE 519-1992

Sets limits for harmonic voltage and currents at the Point of Common Coupling (PCC). It places responsibility on large commercial and industrial consumers.

Voltage Distortion Limits		
Bus Voltage at PCC	**Individual voltage distortion [%]***	**Total voltage distortion [%]**
below 69kV	3.0	5.0
69kV to 138kV	1.5	2.5
Above 138kV	1.0	1.5

* maximum for individual harmonic

Current Distortion Limits						
Maximum odd harmonic current distortion in percent of I_L for general distribution systems (120V – 69kV)						
I_{SC}/I_L	<11	$11\leq n<17$	$17\leq n<23$	$23\leq n<35$	$35\leq n$	TDD
<20	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

I_{SC}- maximum short circuit current at the PCC

I_L- fundamental of the average (over 12 months) maximum monthly demand load current at PCC

TDD – total demand distortion, harmonic current distortion in % of maximum demand load current (15 or 30 minute demand)

IEC 61000-3-2 (IEC 1000-3-2)

It is addresses for small customer equipment. Emphasis on *public, low-voltage and household.*

IEC 1000-3-2 Limits for Class D Equipment		
Harmonic order	**Maximum permissible harmonic current per watt**	**Maximum permissible harmonic current**
N	mA/W	A
3	3.4	2.3
5	1.9	1.14
7	1.0	0.77
9	0.5	0.40
11	0.35	0.33
$13\leq n\leq 39$ (odd har. only)	3.85/n	Refer to class A

IEC 61000-3-4 (IEC 1000-3-4)

It's addresses for larger customers (single and three-phase harmonic limits). It gives a consideration of the short circuit ratio R_{SCC}.

IEC 1000-3-4 limits for three phase equipment						
Minimal R_{SCC}	**Upper limits for harmonic distortion factors**		**Limits for individual harmonic in % of I_1**			
	THD	*PWHD*	I_5	I_7	I_{11}	I_{13}
66	17	22	12	10	9	6
120	18	29	15	12	12	8
175	25	33	20	14	12	8
250	35	39	30	18	13	8
350	48	46	40	25	15	10
450	58	51	50	35	20	15
>600	70	57	60	40	25	18

A.2 MEASURES OF HARMONIC DISTORTION

A distorted periodic current or voltage waveform expanded into a Fourier series expressed as follows.

$$i(t) = \sum_{h=1}^{\infty} I_h \cos\left(h\omega_0 t + \phi_h\right) \qquad \text{(A 1.1)}$$

$$v(t) = \sum_{h=1}^{\infty} V_h \cos\left(h\omega_0 t + \theta_h\right) \qquad \text{(A 1.2)}$$

Where

I_h is the h th harmonic peak current

V_h is the h th harmonic peak voltage

ϕ_h is the h th harmonic current phase

ω_0 is the fundamental angular frequency

A.2.1 Rms Voltage And Rms Current

The expressions for rms voltage and rms current are given by,

$$V_{rms} = \sqrt{\sum_{h=1}^{\infty} V_{hrms}^{2}} \qquad \text{(A.1.3)}$$

$$I_{rms} = \sqrt{\sum_{h=1}^{\infty} I_{hrms}^{2}} \qquad \text{(A 1.4)}$$

Where,

V_{hrms} is the rms harmonic voltage

I_{hrms} is the rms harmonic current

A.2.2 VOLTAGE AND CURRENT DISTORTION FACTORS

Voltage distortion factor or voltage total harmonic distortion is defined as

$$THD_V = \frac{1}{V_1}\sqrt{\sum_{h=2}^{\infty} V_h^2} = \sqrt{\left(V_{rms}/V_{1rms}\right)^2 - 1} \qquad \text{(A 1.5)}$$

Current distortion factor or current total harmonic distortion is defined as

$$THD_I = \frac{1}{I_1}\sqrt{\sum_{h=2}^{\infty} I_h^2} = \sqrt{\left(I_{rms}/I_{1rms}\right)^2 - 1} \qquad \text{(A 1.6)}$$

Where V_1 and I_1 represent the fundamental peak voltage and peak current respectively.

A.3 MICROCONTROLLER CODE

```
#include<pic.h>

#include<lcd.h>

void Adc_Tmr_Init(void);

void adc0(void);

static bit input   @((unsigned) &PORTC*8+0);

static bit output1 @((unsigned) &PORTB*8+0);

static bit output2 @((unsigned) &PORTB*8+1);

static bit output3 @((unsigned) &PORTB*8+2);

static bit output4 @((unsigned) &PORTB*8+3);

unsigned int count,val,count1,a1;

//unsigned char val;

bit a,b;
```

```
void main()

{

TRISC=0x01;

TRISB=0x00;

output1=output2=output3=output4=0;

lcd_init();

//Adc_Tmr_Init();

command(0x80);

lcd_condis("  50Hz Sine.W.  ",16);

command(0xc0);

lcd_condis("with Sqre Pulse.",16);

delay(50000);

while(!input);

while(input);

a=0;

//TMR1ON=1;

while(1)

{

adc0();

//command(0xc0);

//hex_dec1(val);

if(val>40)

{

if(input && !a)
```

```
{
output3=output2=0;
 delay(50);
a=1;
output1=output4=1;
}
if(!input && a)
{
output1=output4=0;
 delay(50);
a=0;
output2=output3=1;
}
}
else output4=output1=output3=output2=0;
}
}
void Adc_Tmr_Init()
{
 ADCON1=0x02;        // 8-channel, Left justified, ADC control
 TRISA=0xff;       // to select the port A as input port
  GIE=1;
  PEIE=1;
  TMR1IE=1;
```

```
   TMR1L=0x05;

   TMR1H=0xff;

   T1CON=0x80;

   TMR1ON=0;

}

void interrupt FUNCTION(void)

{

}

void adc0()

{

//val=0;

//for (j=0; j<10; j++)

{

    ADCON0=0x01;        // Channel select (Cha: 0)

//   ADON=1;            // ADC module ON

    delay(1);

    ADCON0 =0x05;          // selecting a particular channel and making the go/done bit high

    while(ADCON0!=0X01);  // Chk whether conversion finished or not

   val = ADRESH;      // 8 bit value taken into one variable

}

//val= val*2;

//if(val>250) val=250;

//temp1=val;

}
```