ADAPTIVE HYSTERESIS BASED FUZZY CONTROLLED SHUNT ACTIVE POWER FILTER FOR MITIGATION OF HARMONICS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Master of Technology
In
POWER CONTROL AND DRIVES

By

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Rourkela-769008
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CERTIFICATE

This is to certify that the thesis entitled "**Adaptive Hysteresis Based Fuzzy Controlled Shunt Active Power Filter For Mitigation Of Harmonics"**, submitted by **Mr. Chandrasekhar Amara** in partial fulfillment of the requirements for the award of **Master of Technology in Electrical Engineering** with specialization in "**Power Control and Drives**" at National Institute of Technology, Rourkela. A Bona fide record of research work carried out by him under my supervision and guidance. The candidate has fulfilled all the prescribed requirements. The Thesis which is based on candidates own work, has not submitted elsewhere for a degree/diploma.

In my opinion, the thesis is of standard required for the award of a master of technology degree in Electrical Engineering.

Place: Rourkela

Date:

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Chandrasekhar Amara
M.Tech (Power Control and Drive)

Contents

ABSTRACT

Active filters are widely employed in distribution system to reduce the harmonics produced by non-linear loads result in voltage distortion and leads to various power quality problems. In this work the simulation study of a Adaptive hysteresis based fuzzy logic controlled shunt active power filter capable of reducing the total harmonic distortion is presented. The advantage of fuzzy control is that it is based on a linguistic description and does not require a mathematical model of the system and it can adapt its gain according to the changes in load. The instantaneous p-q theory is used for calculating the compensating current. Fuzzy-adaptive hysteresis band technique is adopted for the current control to derive the switching signals for the voltage source inverter. The fuzzy-adaptive hysteresis band current controller changes the hysteresis bandwidth according to the supply voltage and slope of the reference compensator current wave. A fuzzy logic-based controller is developed to control the voltage of the DC Capacitor.

This work presents and compares the performance of the fuzzy-adaptive controller with a conventional fuzzy and PI controller under constant load. The total Harmonic Distortion, Individual harmonic content with respect to % of fundamental in Supply current, source voltage have been analyzed. Various simulation results are presented.

And also the performance of two current control techniques namely adaptive hysteresis current control and fixed hysteresis control techniques are compared with respect to average switching frequency. A neural network control method for regulating the DC Voltage across the capacitor connected to the inverter for harmonic suppression is proposed.

The THD of the source current after compensation is well below 5%, the harmonic limit imposed by the IEEE-519 standard.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Power quality is becoming important due to proliferation of nonlinear loads, such as rectifier equipment, adjustable speed drives, domestic appliances and arc furnaces. These nonlinear loads draw non-sinusoidal currents from ac mains and cause a type of current and voltage distortion called as ‘harmonics’. These harmonics causes various problems in power systems and in consumer products such as equipment overheating, capacitor blowing, motor vibration, transformer over heating excessive neutral currents and low power factor.

Power quality problems are common in most of commercial, industrial and utility networks. Natural phenomena, such as lightning are the most frequent cause of power quality problems. Switching phenomena resulting in oscillatory transients in the electrical supply.

For all these reasons, from the consumer point of view, power quality issues will become an increasingly important factor to consider in order to satisfy good productivity. To address the needs of energy consumers trying to improve productivity through the reduction of power quality related process stoppages and energy suppliers trying to maximize operating profits while keeping customers satisfied with supply quality, innovative technology provides the key to cost-effective power quality enhancements solutions. However, with the various power quality solutions available, the obvious question for a consumer or utility facing a particular power quality problem is which equipment provides the better solution.

1.2 Definition of Power Quality:

Power quality, like quality in other goods and services, is difficult to quantify. There is no single accepted definition of quality power. There are standards for voltage and other technical criteria that may be measured, but the ultimate measure of power quality is determined by the performance and productivity of end-user equipment. If the electric power is inadequate for those needs, then the “quality” is lacking.

Hence power quality is ultimately a consumer-driven issue, and the end user’s point of reference the power quality is defined as “ **Any power problem manifested in voltage, current or frequency deviations that results in failure or misoperation of customer equipment[25]**.

The Power system network is designed to operate at a sinusoidal voltage of a given frequency (typically 50 or 60Hz) and magnitude. Any recordable variation in the waveform magnitude, frequency, or purity is a potential power quality problem.

In practical power system, there is always a close relationship between voltage and current. Even if the generators supply a pure sine-wave voltage, the current passing through the impedance of the system can cause a variety of disturbances to the voltage. For example,

1. Voltage sags are occurred due to the Current resulting from a short circuit or disappear completely, as the case may be.
2. Due to lighting strokes, the resultant currents diverted through the power system causes large-impulse voltages which causes frequent flash over of insulation and leads to other phenomena, such as short circuits.
3. Harmonic-producing loads can cause distorted currents, consequently the voltages are distorted, due to these distorted currents as they are pass through the system impedance. Thus a distorted voltage is presented to other end users.

Therefore, while it is the voltage with which we are ultimately concerned, we must also address phenomena in the current to understand the basis of many power quality problems.

1.3 Causes, effects and solutions for the PQ perturbations [25]:

Perturbation	***Causes***	***Typical Effects***	***Solutions***
Voltage Variations	Load variations and other switching events that cause long-term changes in the system voltages	Premature ageing, preheating or malfunctioning of connected equipment	Line-voltage regulators, UPS, Motor-generator Set
Voltage fluctuations(Flicker)	Arcing condition on the power system(e.g. resistance welder or an electric arc furnace)	Disturbing effect in lighting systems, TV and monitoring equipment.	Installation of filters, static VAR systems, or distribution static compensators.

Perturbation	***Causes***	***Typical Effects***	***Solutions***
Transients	Switching events e.g capacitor, load switching	Blinking, clocks and VCRs	Transient suppressors
	Induced in the distribution circuits by a nearby lighting strike.	Upset permanent and noticeable, requiring, manual reset.	
Sag(dip)	Fault in the network	Malfunctions of electric drives, converters and equipment with an electronic input stage.	UPS , Constant-voltage transformer.
Short interruptions of supply voltage	By excessively large inrush currents.	Relay and contractors can drop out.	Energy storage in electronic equipment.
Swell	Single-line ground failures(SLG), upstream failures, switching off a large load or switching on a large capacitor.	Trip-out of protective circuitry in some power electronic system.	UPS, Power Conditioner.
Long interruptions of supply voltage	Distribution faults	Current data can be lost and the system can be corrupted.	UPS
	Installation failures	After interruption is over, the reboot process, especially on a large and complex system, can last for several hours.	Distributed energy sources.
Harmonic distortion	i) Nonlinear industrial loads: variable –speed drives, welders, large UPS systems, lighting systems.	Overheating and fuse blowing of power factor correction capacitors, Overheating of supply transformers.	Passive and Active Filter.
	ii) Nonlinear residential and commercial loads: Computers, electronic office equipment, electronic devices and lighting.	Tripping of over current protection, overheating of neutral conductors and transformers.	
Voltage unbalance	Less than 2% is unbalanced single-phase loads on a three-phase circuit, capacitor bank anomalies such as a blown fuse on one phase of a three-phase bank. Severe(greater than 5%) can result from single phasing conditions.	Overheating of motors. Skipping some of the six half-cycles that are expected in variable-speed drives.	To reassess the allocation of single-phase loads from the three-phase system.

1.4 Identified and Unidentified Harmonic-Producing Loads:

From three-phase, sinusoidal, balanced voltages non-sinusoidal currents are drawn by the nonlinear loads, these loads are classified as identified and unidentified loads. Arc furnaces, variable speed induction motor drives, and cycloconverters ,high-power diode or thyristor rectifiers are typically mentioned as identified harmonic-producing loads, as the individual nonlinear loads installed by large-power consumers on power distribution systems were identified in many cases. All these identified nonlinear loads generates a huge amount of harmonic current. The point of common coupling (PCC) is normally determined by the utilities of large-power consumers who were installed their own harmonic-producing loads on power distribution systems. At the same time, the amount of harmonic current injected by each consumer will also be determined.

When compared with the actual system currents, the single phase low-power diode rectifier produces a small amount of harmonic current. However, a large amount of harmonics are injected by the multiple low-power diode rectifiers into the power distribution system. The example of an unidentified harmonic-producing load is low-power diode rectifier used in utility interface as an electric appliance is typically considered.

So far, less attention has been paid to unidentified loads than identified loads. Harmonic regulations or guidelines such as IEEE 519-1992 are currently applied, with penalties on a voluntary basis, to keep current and voltage harmonic levels in check. The final goal of the regulations or guidelines is to promote better practices in both power systems an equipment design at minimum social cost.

Table 1.1 List of Identified/Unidentified sources of Harmonic pollution[1]

Sources	**Harmonic pollution**
Unidentified	• TV sets and personal computers • Inverter-based home appliances such as adjustable-speed heat pumps for air conditioning. • Adjustable-speed motor drives.
Identified	• Bulk diode/thyristor rectifiers • Cycloconverters • Arc furnaces

1.5 Fundamental of Harmonic Distortion:

Figure 1.1 illustrates that any periodic, distorted waveform can be expressed as a sum of pure sinusoids. The sum of sinusoids is referred to as a Fourier Series, named after the great mathematician who discovered the concept. The main attractive feature of the Fourier analysis is, it permits to represent a distorted periodic waveform can be represented as an infinite series containing fundamental component (50/60Hz for power systems) and its integer multiples called the harmonic components, DC component. The harmonic component is generally represented by the harmonic number (h) , and is defined as the ratio of that particular harmonic frequency to the fundamental frequency.

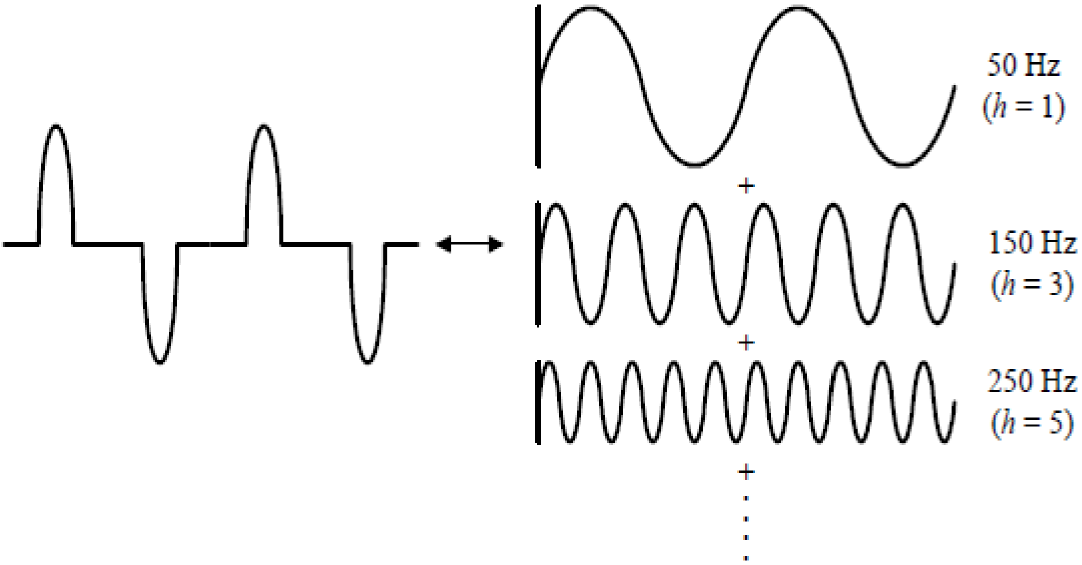


Fig. 1.1 Representation of a distorted waveform by Fourier Series.

Total Harmonic Distortion(THD) is the most preferable harmonic measurement indices to know the harmonic content in the distorted waveform. To know the harmonic distortion in both current and voltage waveforms, this THD formulae as given in equation(1) can be applied, and it is defined as the root-mean-square(rms) value of harmonics divided by the rms value of the fundamental, and then multiplied by the 100% as shown in the following equation.

$$\mathrm{THD} = \frac{\sqrt{\sum_{h>1}^{h_{\max}} M_h^2}}{M_1} \times 100\,\% \quad \ldots\ldots\ldots\ldots\ldots(1)$$

Where M_h is the rms value of harmonic component h of the quantity M .

THD of current varies from a few percent to more than 100%. THD of voltage is usually less than 5%. Below 5% value for Voltage THDs are mostly considered to be acceptable, while THDs above 10% are undoubtedly not acceptable, these will cause problems for sensitive equipment and loads [2].

1.6 Methodology of Research:

In the elaboration of the research, a harmonic analysis of source current distortion has been carried out. It has featured a nonlinear full-bridge diode rectifier with R-L load as a harmonic currents source. The time domain simulation is performed using MATLAB/Simulink simulation package.

Basically the implementation of the control strategy will be done in three steps. In the first step, the required load current and source voltage signals are measured to know the exact information about the system studied. In the second step, by using instantaneous p-q theory the reference compensating currents are obtained. In the third step, by using hysteresis-based current control technique the required gating signals for the solid-state devices are generated.

The performance of the Shunt Active Filter for mitigation of current harmonics in the source current was analyzed with the different combinations of Fixed, Adaptive Hysteresis and Fuzzy-adaptive hysteresis based current control techniques and PI, Fuzzy-Logic controller techniques for closed loop control of DC link capacitor voltage to get the reference current templates.

Finally Neural Network Controller for D.C link capacitor Voltage control is proposed with fixed hysteresis current control technique and the simulation results obtained are compared with the above techniques. The results obtained in the proposed technique were found to be satisfactory in reducing the mitigation of harmonics in the source current.

1.7 Outline of the chapters:

This thesis entitled as “Adaptive Hysteresis Based Fuzzy controlled Shunt Active Power Filter for Mitigation of Harmonics”, Chapter 1 starts with the Introduction of Power Quality and causes, effects and solutions for the PQ perturbations. Fundamental of Harmonic Distortion, varies harmonic producing loads and methodology of research.

Chapter 2, deals with the Harmonic mitigation approaches like Passive, Active, and Hybrid Filter topologies, including their merits and demerits. In this chapter active filter applications depending on Power Quality problems are also discussed.

Chapter 3, deals with the Reference signal estimation techniques such as Frequency domain, time domain approaches and other algorithms like source-current, load-current, voltage detection methods and their applications to active filters are discussed.

Chapter 4 has been dedicated to the discussion of Hysteresis current band controller technique for generation of switching signals to the CC-VSI based APF and its demerits are discussed. Adaptive hysteresis band current controller to overcome the disadvantages in conventional hysteresis current controller technique is also presented..

Chapter 5 is about study and comparison of available conventional controllers such as PI, Fuzzy logic and Neural Network controllers. The merits and demerits of PI Controller and applications of Fuzzy and Neural Network Controllers are also discussed.

Chapter 6 deals with the actual system studied. This chapter discusses about the basic compensation principle, detail study of pq theory for generation of reference currents. DC voltage control, current control techniques implemented are also analyzed. The schematic diagram of proposed control technique is discussed.

Chapter 7 is Simulations and results of the system studied. It also includes the discussions of the results and conclusions about the work carried out. Different plots have been plotted and the results are compared with proposed technique with conclusion.
This thesis ends with future scope and references.

CHAPTER 2

HARMONIC MITIGATION APPROACHES

2.1 Introduction:

This section discusses general properties of various approaches for harmonic distortion mitigation. The advantages, disadvantages, limitations and applications depending on different power quality problems of these approaches are also compiled in this section.

2.2 Harmonic Mitigation Approaches:

In power distribution systems harmonic mitigation can be done through the following techniques:

1. Passive filter.
2. Active power filter.
3. Hybrid active power filter.

The concept of passive filtering is the simplest solution to reduce the harmonic distortion [3]-[5]. Although simple, these conventional solutions that use passive elements do not always respond correctly to the dynamics of the power distribution systems [6]. From so many years, these Passive filters have developed to high level of sophistication. Passive filters are tuned at one or more frequencies to suppress the harmonics in power distribution system. The main disadvantages with the use of these passive filters for high power level applications makes the filter size heavy bulky, and also the passive filters may cause resonance, thus affecting the stability of the power distribution systems [7]. Due to these problem faced with the passive filters makes their applications limited and may not be able to meet future requirements of a particular Standard.

Due to remarkable growth in power electronics makes the use of active power filters (APF) as the dynamic solution for mitigation of harmonics. The fundamental principle of APF is to utilize advances in power electronics switches to produce equal and opposite currents signals that cancel the harmonic currents from the nonlinear loads [8]. However the high order harmonics are not filtered effectively by using digital methods. This is because of the sampling rate limitation for implementation of hardware in real-time application [9]. Moreover, the APF application with the use of fast switching transistors (i.e. MOSFETs, IGBTs) causes switching frequency noise to appear in the compensated source current. Additional filtering is required to minimize this switching frequency noise which causes interference with other sensitive equipments.

The concept of hybrid APF has been proposed and developed by so many researchers. In this hybrid APF filtering of harmonics is divided between the two filters. Lower order harmonics are cancelled by the APF, while the higher order harmonics are eliminated through high pass filters. The main basic objective of hybrid APF is to improve the filtering performance of high-order harmonics while providing a cost-effective low order harmonic suppression.

2.3 Passive Filtering of Harmonic:

Conventional solutions to the harmonic distortion problems have existed for a long time. To mitigate the harmonic distortion this passive filtering is the simplest conventional solution [2]-[6]. Passive filters consists of mainly inductance, capacitance, and resistance elements configured and tuned to control particular frequency of harmonics. Common types of passive filters and their configurations are shown in figure 2.1.

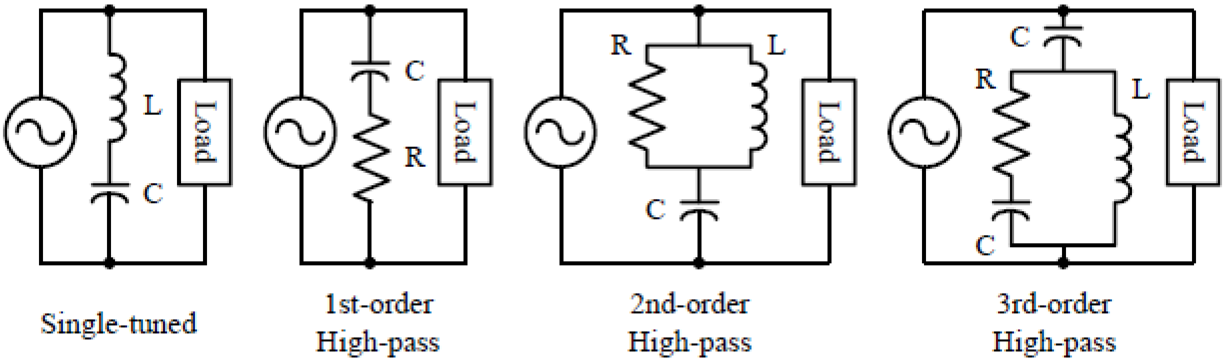


Fig. 2.1: Common types of passive filters and their configurations

Another popular type of passive filter is the high-pass filter (HPF) [2], [4]. A large percentage of all harmonics above its corner frequency are allowed through HPF. As shown in Figure 2.1, HPF typically takes on one of the three forms. The first-order, which is characterized by large power losses at fundamental frequency, is rarely used. The second-order HPF is the simplest to apply while providing good filtering action and reduced fundamental frequency losses [6]. The filtering performance of the third-order HPF is superior to that of the second-order HPF. However, for low- voltage or medium-voltage applications the third-order HPF is not commonly used because of the economic, complexity, and reliability factors do not justify them [5].

Although compare to Active power filters, the passive filters are simple and least expensive, but have several inherent shortcomings are there. For mitigation of lower order harmonics the requirement of filter components are very bulky. And also the compensation characteristics of these filters are highly effected by the source impedance. Due to this, the filter design is highly dependent on the power system in which it is connected [5]. The passive filter is also known to cause resonance, thus affecting the stability of the power distribution systems [6], [7].

The filtering characteristics are affected by the frequency variation of the power distribution system and tolerances in components values. If the frequency variation is high, then the size of the components become impractical [6], [7]. As the regulatory requirements become more stringent, the passive filters might not be able to meet future revisions of a particular Standard.

2.4 Active Filtering of Harmonic

Active Filters are commonly used for providing harmonic compensation to a system by controlling current harmonics in supply networks at the low to medium voltage distribution level or for reactive power or voltage control at high voltage distribution level. These functions may be combined in a single circuit to achieve the various functions mentioned above or in separate active filters which can attack each aspect individually. The block diagram presented in figure 2.2 shows the basic sequence of operation for the active filter. This diagram shows various sections of the filter each responding to its own classification.

The reference signal estimator monitors the harmonic current from the nonlinear load along with information about other system variables. The reference signal from the current estimator, as well as other signals, drives the overall system controller. This in turn provides the control for the PWM switching pattern generator. The output of the PWM pattern generator controls the power circuit through a suitable interface. The power circuit in the generalized block diagram can be connected in parallel, series or parallel/series configurations, depending on the transformer used.

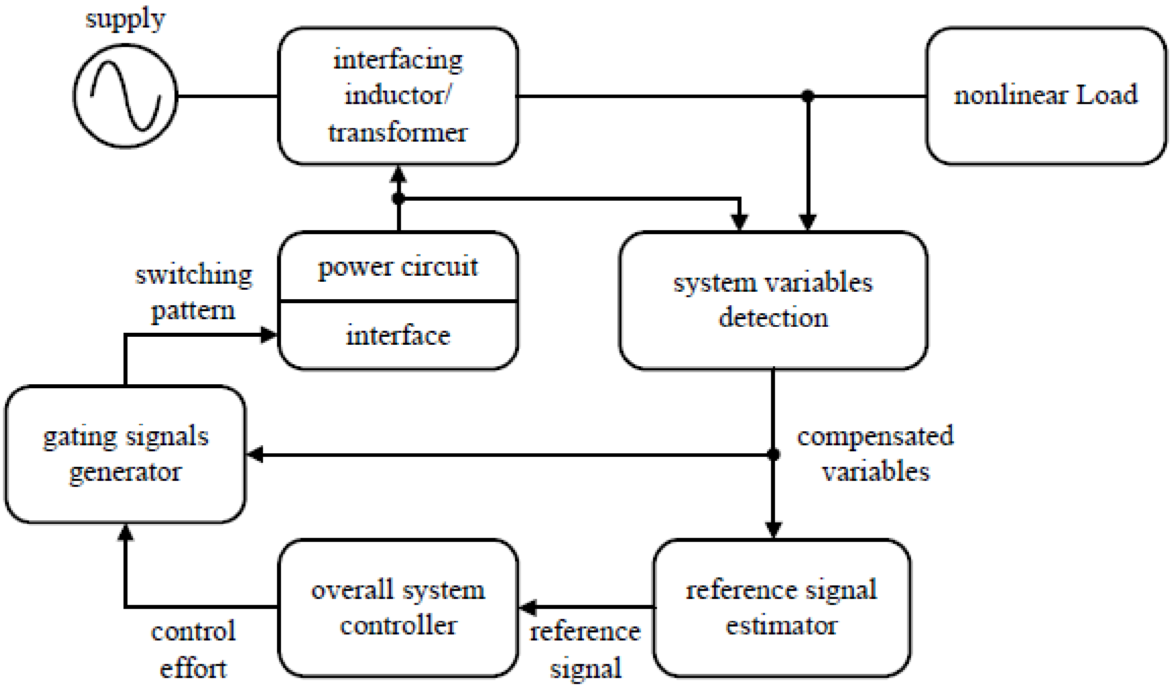


Figure 2.2 Generalized block diagram for APF

There are large number of advantages of APFs compare to passive filters. They will suppress supply current harmonics and also the reactive currents. Moreover, these active filters do not cause resonance like passive filters in the power distribution systems. Consequently, the APFs performances are independent of the power distribution system properties [7].

On the other hand, APFs have some drawbacks. There is a lot of research and developments are required to make this technology well improved. The main disadvantage of APF is, it requires the fast switching of high currents in the power circuit of the APF. Which results in a high frequency noise that may cause an electromagnetic interference (EMI) in the power distribution systems. APF used in several power circuit configurations as illustrated in the block diagram shown in Figure 2.3. In general, they are mainly divided into three categories, namely shunt APF, series APF and hybrid APF.

Active power filters can be classified based on the following criteria:

1. Power rating and speed of response required in compensated systems;
2. Power-circuit configuration and connections;
3. System parameters to be compensated;
4. Control techniques employed; and
5. Technique used for estimating the reference current/voltage.

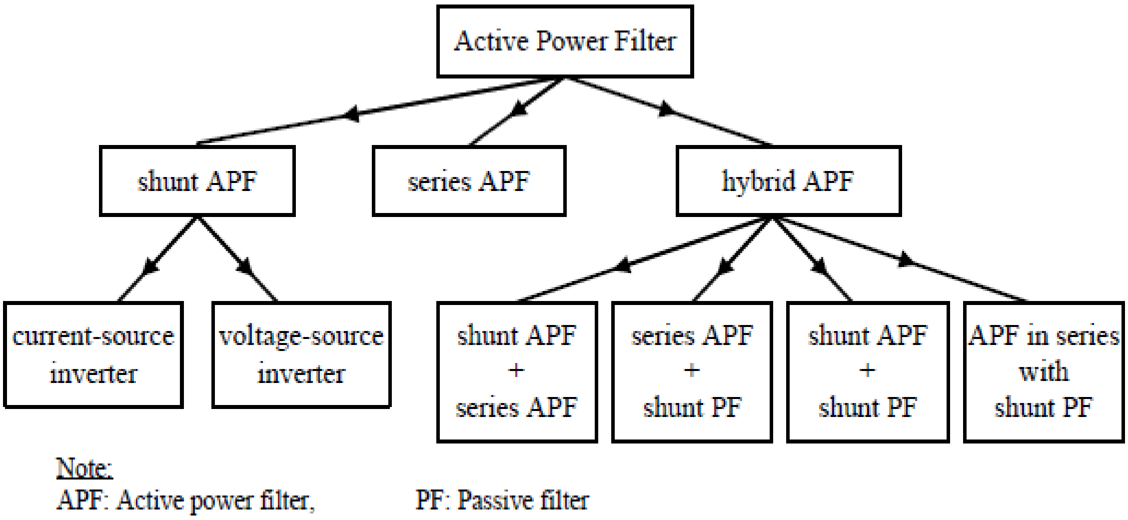


Fig. 2.3 Subdivision of APF according to power circuit configurations and connections

2.4.1 Shunt Active Power Filter:

Shunt active filters are by far the most widely accept and dominant filter of choice in most industrial processes. Figure 2.4 show the system configuration of the shunt design. The active filter is connected in parallel at the PCC and is fed from the main power circuit. The objective of the shunt active filter is to supply opposing harmonic current to the nonlinear load effectively resulting in a net harmonic current. This means that the supply signals remain purely fundamental. Shunt filters also have the additional benefit of contributing to reactive power compensation and balancing of three-phase currents. Since the active filter is connected in parallel to the PCC, only the compensation current plus a small amount of active fundamental current is carried in the unit. For an increased range of power ratings, several shunt active filters can be combined together to withstand higher currents.

The APF consists of a DC-bus capacitor (C_f), power electronic devices and a coupling inductors (L_f). Shunt APF acts as a current source for compensating the harmonic currents due to nonlinear loads. This is achieved by “shaping” the compensation current waveform (i_f), using the Current Controlled- VSI. The required compensating currents are obtained by measuring the load current (i_L) and subtracting it from a sinusoidal reference. The aim of shunt APF is to obtain a sinusoidal source current (i_s) using the relationship: $\boldsymbol{i_s = i_L - i_f}$.

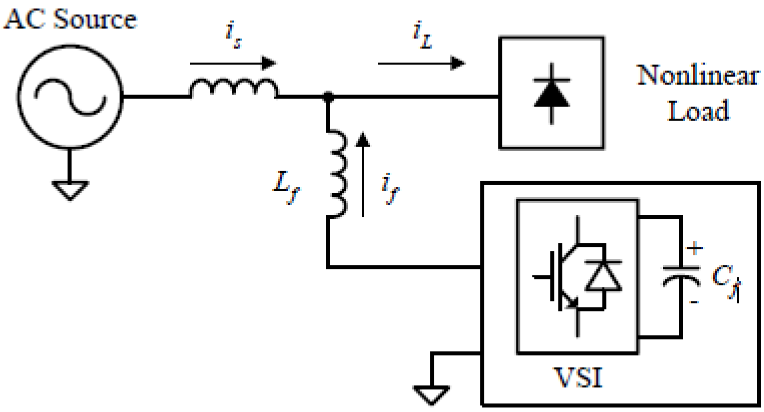


Fig.2.4 Principal configuration of VSI based shunt APF

If the nonlinear load current can be written as the sum of the fundamental current component ($i_{L,f}$) and the current harmonics ($i_{L,h}$) according to

$$i_L = i_{L,f} + i_{L,h} \quad \text{........(1)}$$

then the compensation current injected by the shunt APF should be

$$i_f = i_{L,h} \quad \text{.........(2)}$$

the resulting source current is

$$is = i_L - i_f = i_{L,f} \quad \text{........(3)}$$

From the above equation(3) the source current contains only the fundamental component of the nonlinear load current and thus free from harmonics. When the shunt APF performs harmonic filtering , the ideal source current for a nonlinear load connected is shown in figure 2.5. In this way the shunt APF completely cancels the current harmonics from the nonlinear load, thus results in a harmonic free source current.

The shunt APF can be considered as a varying shunt impedance from the nonlinear load current point of view. For the harmonic frequencies the impedance is zero, or at least small, and infinite in terms of the fundamental frequency. Due to this effect there is a considerable in voltage harmonics, because the harmonic currents flowing through the source impedance are reduced. The current carried by the Shunt APFs is the sum of the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. Reactive power compensation is also possible through the Shunt APF. Moreover for higher power rating applications, it is also possible to connect several shunt APFs in parallel to meet the requirement for higher currents.

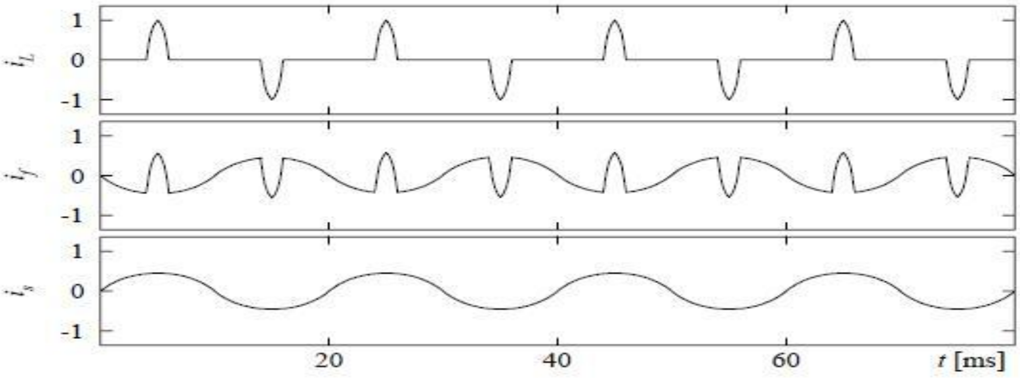


Fig.2.5 Operating principle of Shunt APF for harmonic filtering

2.4.2 Series Active Power Filter

Figure 2.6 show the basic connection diagram for series APF. The main objective of the series active filter is to maintain a pure sinusoidal voltage waveform across the load. This is achieved by producing a PWM voltage waveform which is added or subtracted against the supply voltage waveform. The choice of power circuit used in most cases is the voltage-fed PWM inverter without a current minor loop. Unlike the shunt filter which carries mainly compensation current, the series circuit has to handle high load currents. This causes an increased rating of the filter suitable to carry the increased current. Series filters offer the main advantage over the shunt configuration of achieving ac voltage regulation by eliminating voltage-waveform harmonics. This means the load contains a pure sinusoidal waveform only.

The series APF can be thought of as a harmonic isolator as shown in Figure 2.7. By proper control of this Series APF there is no current harmonics can flow from nonlinear load to source, and vice versa.

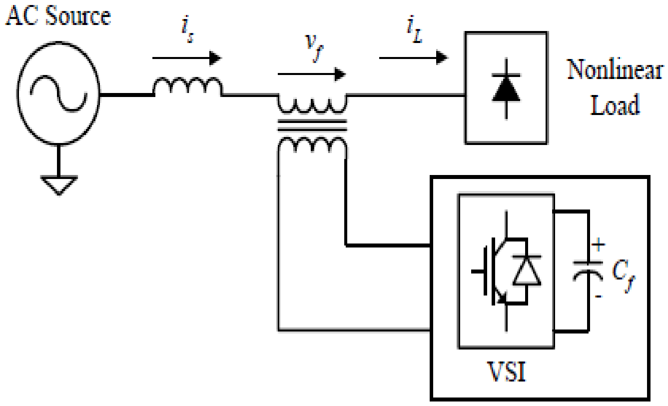


Fig. 2.6: Principle configuration of VSI based Series APF

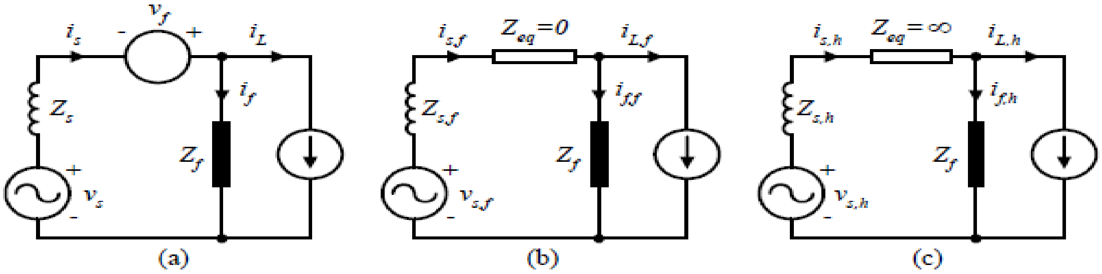


Fig. 2.7: Operation principle of series APF (a) Single phase equivalent of series APF , (b) Fundamental equivalent circuit, and (c) harmonic equivalent circuit.

These Series APFs are not commonly used in power system like the shunt APF [10]. As the load currents handled by the series APF are large. Due to this high capacity of load currents makes the current ratings of series APF considerably compared with shunt APF, particularly in the secondary side of the interfacing transformer. Because of I^2R losses will increase. However, the main advantage of series APF when compared to shunt one is that they are ideal for voltage harmonic mitigation. It provides a pure sinusoidal waveform to the load, which is necessary for voltage sensitive devices like power system protection devices. With this feature, series APFs are widely employed in improving the quality of the source voltage.

2.5 Hybrid Active Power Filter:

Previously, for APF operation many of the controllers are implemented based on analogue circuits [7]. Due to this, the performance of the APF is effected by the signal drift [9]. Digital controllers using DSPs or microcontrollers are preferable, primarily due to its flexibility and immunity to noise. But the high-order harmonics are not filtered effectively by using digital methods. This happens because of the hardware limitation of sampling rate in real-time application [9]. Moreover, the utilization of fast switching power electronic switches (i.e. MOSFETs, IGBTs) in APF application causes switching frequency noise to appear in the compensated source current. Additional filtering circuit is required to reduce this switching frequency noise and to prevent interference with other sensitive equipments

The above problems discussed with APFs can be overcome with the help of hybrid APF configuration. These hybrid APFs are nothing but the combination of APFs and passive filters. Hence these Hybrid APFs gives the advantages of both the passive and APFs and to provide improved performance and cost-effective solutions.

Hybrid APFs Combinations are can be designed to compensate for higher powers without excessive costs for high-power switching. But the major disadvantage of this configuration is the fact that passive filters can only be tuned for a specific predefined harmonic and thus cannot be easily changed for loads which have varying harmonics

As shown in figure 2.8(a), this hybrid APF is a combination of shunt APF and a passive filter connected in parallel with the nonlinear load. Thus the objective function of the Hybrid APF is divided into two parts i.e the lower order harmonics are filtered by the shunt APF, while the higher order harmonics are filtered by the passive High Pass filter

As shown in figure 2.8 (b) the system configuration of hybrid series APF is the combination of series APF and shunt passive filter. By injection of controller harmonic voltage source this hybrid series active filter is controlled to act as a harmonic isolator between the source and nonlinear load. This type of hybrid active filter is controlled in such a way that it offers zero impedance at fundamental frequency and high impedance at all undesired harmonic frequencies. Passive filters are often easier and simple to implement and do not require any control circuit. This, deserves to be most beneficial.

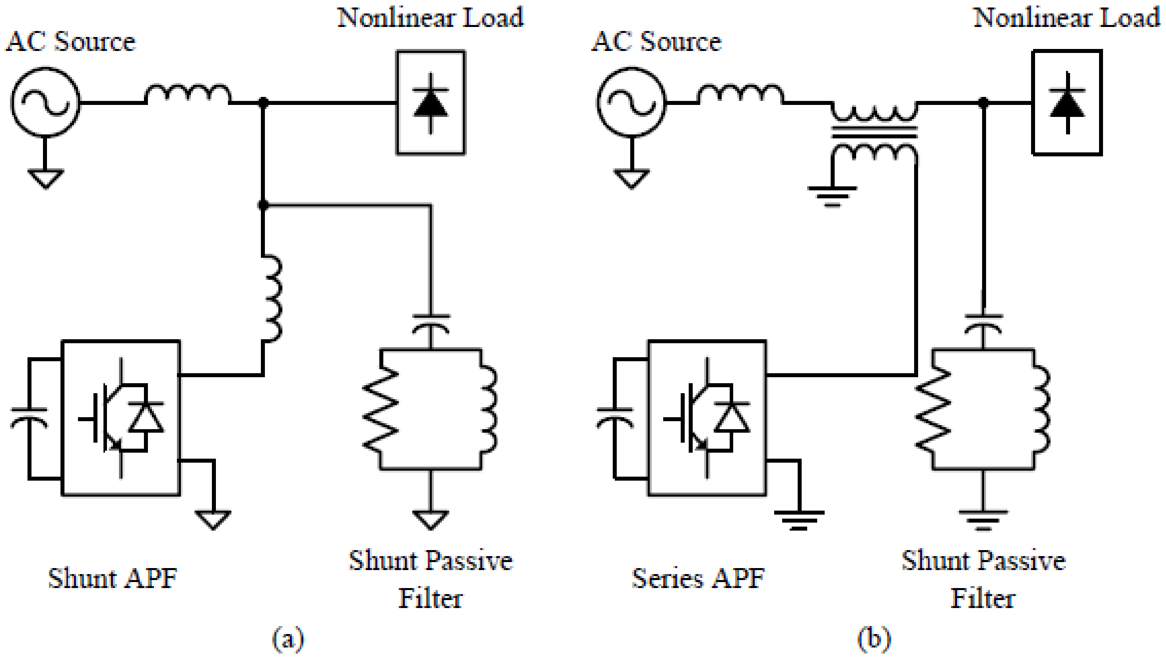


Fig. 2.8 Hybrid APFs: (a) Combination of Shunt APF and Shunt Passive Filter and (b) Combination of Series APF and Shunt passive Filter.

2.6 Active filter application depending on power quality problems:

Depending on the particular application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (shunt-series type). These filters can also be combined with passive filters to create hybrid power filters as given in Table (2.1).

Table 2.1 Active filter application depending on power quality problems.

Active Filter Connection	Source of Problem	
	Load effect on AC Supply	**AC Supply effect on Load**
Shunt	Current Harmonic Filtering	
	Reactive current Compensation	
	Current Unbalance	
	Voltage Flicker	
Series	Current Harmonic Filtering	Voltage Sag/Swell
	Reactive Current Compensation	Voltage Unbalance
	Current Unbalance	Voltage interruption
	Voltage Flicker	Voltage flicker
	Voltage Unbalance	Voltage notching
Series-shunt	Current Harmonic Filtering	Voltage Sag/Swell
	Reactive Current Compensation	Voltage Unbalance
	Current Unbalance	Voltage interruption
	Voltage Flicker	Voltage flicker
	Voltage Unbalance	Voltage notching

2.7 Conclusion

It is very difficult to compare the cost of active filters to passive filters. Passive filters do not approach the harmonic reduction performance level of active filters. Active filter performance is not dependent upon source impedance, but rather on the harmonic producing loads attached. When active filters are applied as bus solutions where multiple nonlinear loads are present, the active filter is less costly and more effective than any other device, and requires less physical space. Added future costs are similar to those of other power electronic devices like VFD and UPS [11]

Active power filters are typically based on GTOs or IGBTs, voltage source PWM converters, connected to medium- and low-voltage distribution systems in shunt, series, or both topologies at the same time.

In comparison to conventional passive LC filters, active power filters offer very fast control response and more flexibility in defining the required control tasks for particular applications. The selection of equipment for improvement of power quality depends on the source of the problem (Table 2.1). If the objective is to reduce the network perturbations due to distorted load currents, the shunt connection is more appropriate. However, if the problem is to protect the consumer from supply-voltage disturbances, the series-connected power conditioner is most preferable. The combination of the two topologies gives a solution for both problems simultaneously [12].

CHAPTER 3

Reference Signal Estimation Techniques

3.1 Introduction

The technique used for generation of reference current signals is the important key component that ensures the correct operation of APF. This calculation of reference signal estimation is based on the gathering accurate system information through detection of voltage/current signals. The voltage variables required are AC source voltage , DC-bus voltage of the APF is to be sensed. And the typical current variables to be sensed are load current, AC source current, compensation current and DC-link current of the APF. Reference signals estimation in terms of voltage/current levels are estimated in frequency-domain or time-domain based on these system variables, feedbacks.

This section presents the considered reference signal estimation techniques, and small description is provided for each regarding their basic features. The below figure illustrates the considered reference signal estimation techniques. These techniques cannot be considered to belong to the control loop since they perform an independent task by providing the controller with required reference for further processing.

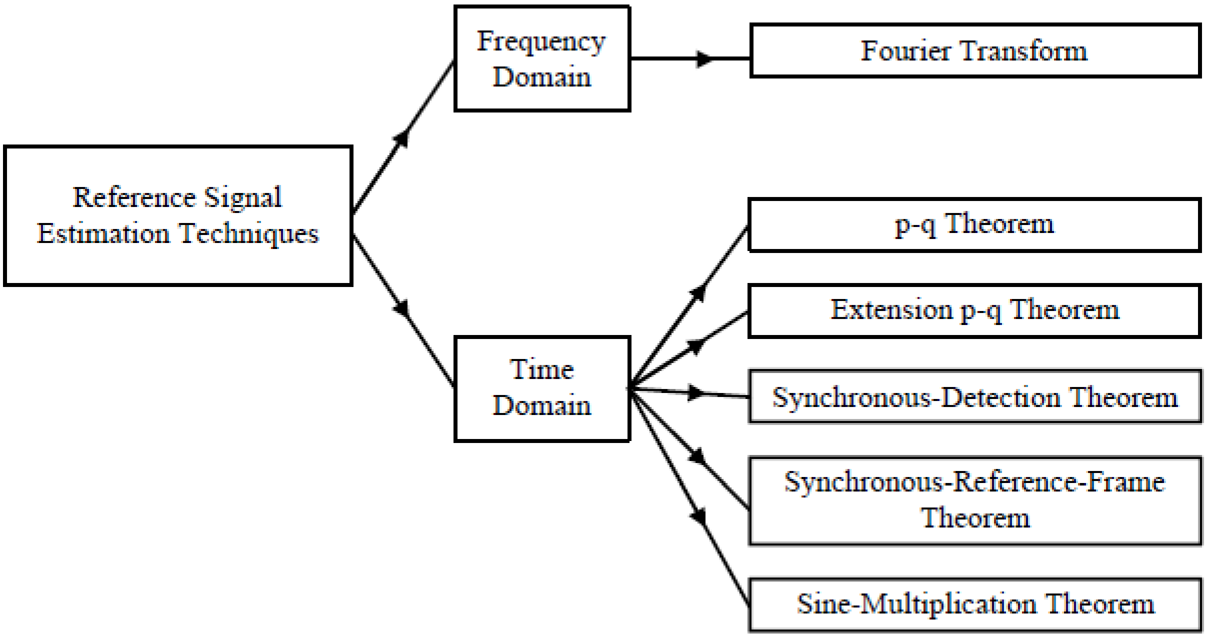


Fig. 3.1 : Subdivision of reference signal estimation techniques

3.2 Frequency Domain approaches:

The frequency-domain methods are mainly based on Fourier analysis, these are arranged in such a manner that this concept will provide quick possible results with a reduced number of calculations, to allow a real-time implementation in DSP's. Once the Fourier transform is taken, the APF converter-switching function is computed to produce the distortion canceling output. With this strategy the APF switching frequency must be more than twice the highest compensating harmonic frequency. This strategy has a poorer dynamic response and it not as widely used. Reference Signal estimation in frequency-domain is suitable for both single and three phase systems.

3.2.1 Conventional Fourier and FFT algorithms:

Using the Fast Fourier Transform (FFT), the harmonic current can be calculated by eliminating the fundamental component from the transformed current signal and then the inverse transform is applied to obtain a time-domain signal. The main disadvantage of this system is the time delay in system variables sampling and computation of Fourier coefficients. This makes it impractical for real-time application with dynamically varying loads. Therefore, this technique is only suitable for slowly varying load conditions.

3.2.2 Modified Fourier series techniques:

The principle behind this technique is that only the fundamental component of current is calculated and this is used to separate the total harmonic signal from the sampled load-current waveform. The practical implementation of this technique relies on modifying the main Fourier series equations to generate a recursive formula with a sliding window. This technique is adapted to use two different circular arrays to store the components of the sine and cosine coefficients computed every sampling sub cycle. The newly computed values of the desired coefficient are stored in place of the old ones and the overall sums of the sine and cosine coefficients are updated continuously. The computation time is much less than that of other techniques used for single-phase applications. This technique is equally suitable for single- or three-phase systems.

3.3 Time Domain approaches:

The following subdivisions of time-domain approaches are mainly used for three-phase systems except for the fictitious-power-compensation technique which can be adopted for single- or three-phase systems. The time-domain methods are mainly used to gain more speed or fewer calculations compared to the frequency-domain methods.

3.3.1 Instantaneous Reactive-power Theorem:

Instantaneous power theory determines the harmonic distortion from the instantaneous power calculation in a three-phase system, which is the multiplication of the instantaneous values of the currents and voltages [1].

The values of the instantaneous power *p* and *q*, which are the real and respective imaginary powers, contain dc and ac components depending on the existing active, reactive and distorted powers in the system. The dc components of *p* and *q* represent the active and reactive powers and must be removed with high-pass filters to retain only the ac signals. The ac components converted by an inverse transformation matrix to the abc-frame represent the harmonic distortion, which is given as the reference for the current controller. This operation takes place only under the assumption that the three-phase system is balanced and that the voltage waveforms are purely sinusoidal.

3.3.2 Extension Instantaneous Reactive-power Theorem:

The conventional p-q theorem is applicable for three-phase unsymmetrical and distorted voltage systems after some modifications by Komatsu and Kawabata. In this theorem, for instantaneous reactive power calculation, the source voltages are shifted by 90°. Instead of the AC components in conventional p-q theorem, the DC components are extracted using low-pass filters (LPFs) and taking inverse transformation to obtain the compensation reference signals in terms of either currents or voltages. The main advantage of this technique is that it is simpler to find three-phase instantaneous reactive power than the conventional p-q theorem.

This technique is also suitable for single-phase APF systems. The instantaneous active power of the load can be derived as

$$\text{p}= v_s(t).i_L(t) = \overline{p} + \tilde{p} \text{……..(1)}$$

For a three phase system with or without neutral conductor in the steady state or during transients, the three phase instantaneous active power describes the total instantaneous energy flow per second between two subsystems.

The instantaneous reactive power of the load can be derived as

$$q = v_s'(t).i_L(t) = \bar{q} + \tilde{q} \text{ ....(2)}$$

Where $v_s'(t)$ denotes the source voltage shifted by 90^0
The imaginary power q is proportional to the quantity of energy that is being exchanged between the phases of the system. It does not contribute to the energy transfer between the source and load at any time.

The DC components ($\bar{p}$ and $\bar{q}$) are extracted from the derived instantaneous active and reactive power using LPFs. The extracted DC components are then used for compensation reference signal estimation. It is clearly seen that the resulting equations for the instantaneous active and reactive power of the load based on extension p-q theorem are simpler.

3.3.3 Synchronous-Detection Theorem:

This technique is based on the fact that the three phase currents are sinusoidal and balanced, in phase with the source voltages irrespective of the load variations. And accordingly, the average power is calculated and divided equally between the three phases. In respect to the supply voltage the signal is then synchronized for each phase. However, this concept is easy to implement, and have a drawback is that it depends to a great extent on the harmonics in the voltage signal.

3.3.4 Synchronous-Reference-Frame Theorem:

This algorithm is based on Park transformations to transform the three phase system from a stationary reference frame into synchronously rotating direct, quadrature and zero-sequence components[9],[13]. These can easily be analyzed because of the fundamental-frequency component is transformed into DC quantities. The three phase system active and reactive components are represented by the direct and quadrature components respectively.

This method is applicable only for three-phase system. As the controller deals with the DC quantities only, hence the system is very stable. The computation is instantaneous but incurs time delays in filtering the DC quantities .

3.3.4 Sine-Multiplication Theorem:

This method is based on the process of multiplying the current signal by a sine wave of the fundamental frequency and integrating the result to obtain real fundamental current of the nonlinear load[14]. The difference between the instantaneous nonlinear load current and this fundamental component current is applied as the command signal for the APF. This technique eliminates time delay but, the performance is still slow (more than one complete mains cycle) because of integration and sampling. This technique is similar to the Fourier techniques presented above; This technique is implemented differently. It is applicable for both single and three phase systems.

3.4 Other algorithms:

Three kinds of Harmonic detection methods in the time domain have been proposed for shunt active filters acting as current source i_{AF} .Taking into the account the polarity of the current i_S, i_L and i_{AF} in the Fig3.2 shown gives

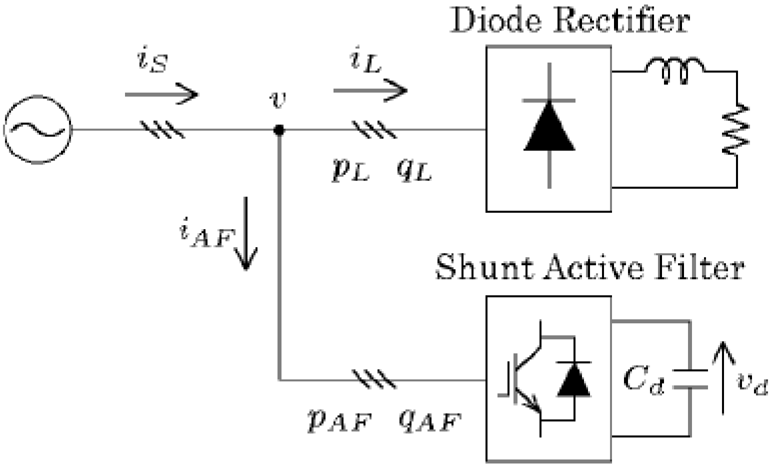


Fig 3.2 Shunt Active Filter

Load -current detection $i_{AF} = -i_{Lh}$

Supply - current detection $i_{AF} = -K_s \cdot i_{sh}$

Voltage detection $i_{AF} = K_v \cdot V_h$

Note that Load-current detection is based on feed forward control, while supply-current detection and voltage detection are based on feedback control with gains K_s and K_v, respectively. Load-current detection and supply-current detection are suitable for shunt active filters installed in the vicinity of one or more harmonic-producing loads by individual consumers. Voltage detection is suitable for shunt active filters that will dispersed on power distribution systems by utilities, because the shunt active filter based on voltage detection is controlled in such a way to present infinite impedance to the external circuit for the fundamental frequency, and to present a resistor with low resistance $1/K_V$ (Ω) for harmonic frequencies.

Supply-current detection is the most basic harmonic detection method for series active filters acting as a voltage source V_{AF}. Referring to Fig 3.3 yields

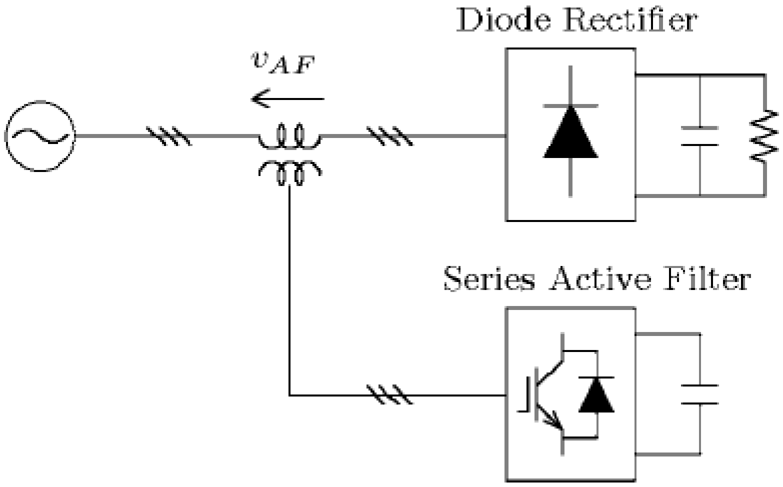


Fig. 3.3 Series Active Filter

Supply-current detection: $V_{AF} = G.\ i_{sh}$

The series active filter based on supply current detection is controlled in such a way to present zero impedance to the external circuit for fundamental frequency and to present a resistor with high resistance of G(Ω) for the harmonic frequencies.

3.5 CONCLUSION:

There are numerous optimization and estimation techniques, and all the utilities and libraries for estimation can be used to perform the task. However some new methods arise, such as the neural network and adaptive-estimation techniques which are fairly accurate and have, of course, much better response. Unfortunately, presently available control hardware is not suitable for implementation of these techniques.

CHAPTER 4

HYSTERESIS BAND CURRENT CONTROLLER

4.1 Introduction

Active power filter control includes two main blocks first block includes calculation of reference compensation currents from system and the second block includes the control strategy to inject the reference compensation currents at 180^0 into the system. In this work reference currents are generated using instantaneous p-q method and gating signals are derived to CC-VSI based Shunt Active power filter by using hysteresis current control strategy.

APF eliminates system harmonics through injecting a current to the system that is equal to the load harmonic current; therefore the system side will almost have no harmonic current remaining. Since the load harmonics to be compensated may be very complex and changing rapidly and randomly, APF has to respond quickly and work with high control accuracy in current tracking. Moreover in order to keep high safety and efficiency in APF operation, the required voltage source inverter(VSI) switching frequency and dc source voltage, which are highly relevant to the current tracking method used should as low as possible. It is clear that APF output current control technique is the key issue of its performance and efficiency.

4.2 Current Control Techniques for Generation of Gating Signals

The applications of three-phase voltage-source pulse width modulated (VS-PWM) converters are mainly applied to control of ac motor drives, high power factor ac/dc converters, active filters, uninterruptible power supply (UPS) systems, and ac power supplies have a control structure consisting of an internal current feedback loop. Therefore, the performance of the converter system is mainly depends on the quality of the applied current control strategy. Therefore, in modern power electronics the current control of PWM converters are most important subject.

In comparison to conventional open-loop voltage PWM converters, the current controlled PWM (CC-PWM) converters have the following advantages:

1) control of instantaneous current waveform and high accuracy;
2) peak current protection;
3) overload rejection;
4) extremely good dynamics;
5) compensation of effects due to load parameter changes (resistance and reactance);
6) compensation of the semiconductor voltage drop and dead times of the converter;
7) compensation of the dc-link and ac-side voltage changes.

Development of PWM current control methods is still in progress.

4.2.1 Generation of Gating Signals to the Devices of the APF

The third stage of control of the APF's is to generate gating signals for the solid-state devices of the APF based on the derived compensating commands, in terms of voltages or currents. A variety of approaches, such as hysteresis-based current control, PWM current or voltage control, deadbeat control, sliding mode of current control, fuzzy-based current control, etc., are implemented, to obtain the control signals for the switching devices of the APF's [15].

Basic Scheme of CC-PWM : The main objective of the control scheme in a CC-PWM converter is to force the currents in a three-phase ac load to follow the reference signals. By comparing the command i_A* (i_B*,i_C*) and measured i_A (i_B,i_C) instantaneous values of the phase currents, the CC generates the switching states T_A (T_B,T_C) for the converter power devices which decrease the current errors. Hence, in general, the CC implements two tasks: error compensation (decreasing e_A,e_B,e_C) and modulation (determination of switching states T_A,T_B,T_C .

Basic Requirements and Performance Criteria: The accuracy of the CC can be evaluated with reference to basic requirements, valid in general, and to specific requirements, typical of some applications. Basic requirements of a CC are the following:

1) No phase and amplitude errors (ideal tracking) over a wide output frequency range;
2) To provide high dynamic response of the system;
3) Limited or constant switching frequency to guarantees APF operation of converter semiconductor power devices;
4) Low harmonic content;
5) Good dc-link voltage utilization.

Note that some of the requirements, e.g., fast response and low harmonic content, contradict each other.

Various techniques, different in concept, have been described in two main groups:

1. Linear and
2. Nonlinear.

The first includes proportional integral (stationary and synchronous) and state feedback controllers, and predictive techniques with constant switching frequency. The second comprises bang-bang (hysteresis, delta modulation) controllers and predictive controllers with on-line optimization. New trends in the current control are neural networks and fuzzy-logic , adaptive based controllers are discussed, as well.

4.2.2 LINEAR CONTROLLERS:

The linear controllers operate with conventional voltage type PWM modulators [16]. In contrast to the nonlinear controllers, linear controller schemes have clearly separated current error compensation and voltage modulation parts. This concept allows us to exploit the advantages of open-loop modulators (sinusoidal PWM, space-vector modulator, and optimal PWM) which are constant switching frequency, well-defined harmonic spectrum, optimum switch pattern, and dc-link utilization. Also, full independent design of the overall control structure, as well as open-loop testing of the inverter and load, can be easily performed. In the linear group, the following controllers are described: PI stationary and synchronous, state feedback, and predictive with constant switching frequency.

In general, thanks to the use of PWM modulators, the linear controllers make a well-defined harmonic spectrum available, but their dynamic properties are inferior to those of bang-bang controllers.

4.2.3 NONLINEAR CONTROLLERS:

The nonlinear CC group includes hysteresis, DM (Density Modulation), and on-line optimized controllers. Also, neural networks (NN‘s) and fuzzy logic controllers (FLC‘s) belong to the class of nonlinear CC.

***Hysteresis Current Controllers**:* Hysteresis-band PWM is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a hysteresis band. Hysteresis control schemes are based on a nonlinear feedback loop with two level hysteresis comparators [Fig. (4.1)] [17]. The switching signals are produced directly when the error exceeds an assigned tolerance band [Fig.(4.2)] [17]. The following figure shows the operation principle of the hysteresis modulation/control scheme. The controller generates the sinusoidal reference current of desired magnitude and frequency that is compared with the actual line current. If the current exceeds the upper limit of the hysteresis band, the upper switch of the inverter arm is turned off and the lower switch is turned on. As a result, the current starts to decay. If the current crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned off and the upper switch is turned on. As a result, the current gets back into the hysteresis band [17]. Hence, the actual current is forced to track the reference current within the hysteresis band.

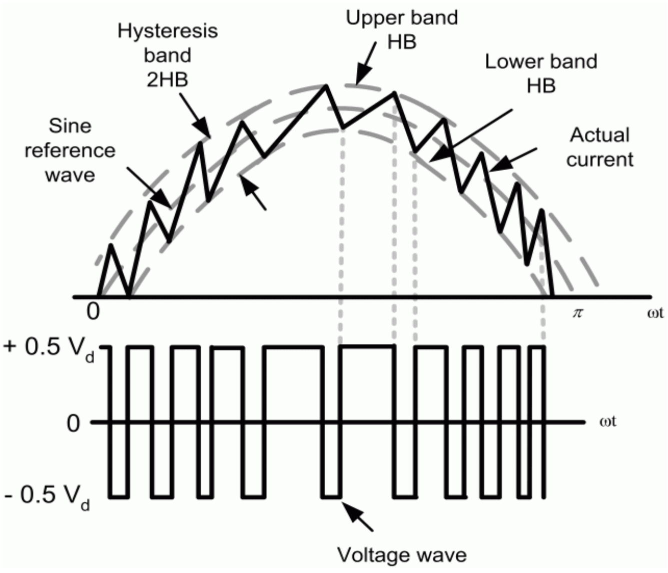


Fig.. 4.1 Principle of hysteresis controller

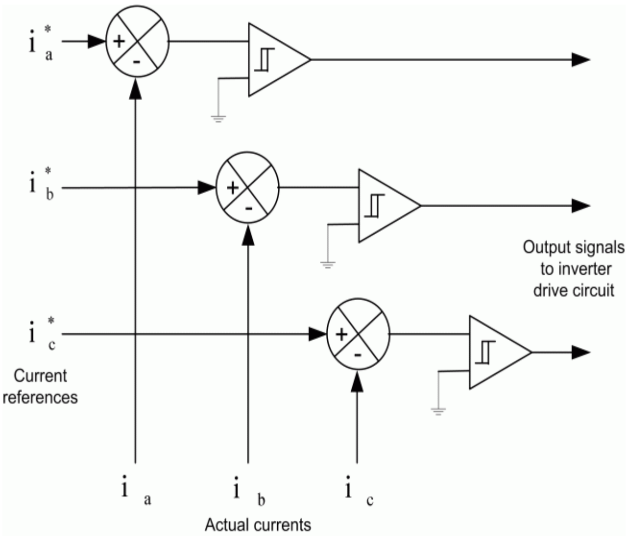


Fig. 4.2 Typical Hysteresis Current Controller operation

a) Variable switching frequency controllers: Among the main advantages of hysteresis CC are simplicity, outstanding robustness, lack of tracking errors, independence of load parameter changes, and extremely good dynamics limited only by switching speed and load time constant. However, this class of schemes, also known as free running hysteresis controllers , has the following disadvantages.

1) Such as PWM frequency is not constant(varies within a band) and as a results in acoustic noise and difficulty in designing the input filters. However, there are device limitations and increasing the switching frequency causes increased switching losses, and EMI related problems. Hence an adaptive hysteresis band can alleviate this problem.

2) The operation is somewhat rough, due to the inherent randomness caused by the limit cycle; therefore, protection of the converter is difficult [18], [19].

b) Constant switching frequency controllers: A number of proposals have been put forward to overcome variable switching frequency. The tolerance band amplitude can be varied, according to the ac-side voltage, or by means of a PLL control.

Although the constant switching frequency scheme is more complex and the main advantage of the basic hysteresis control namely, the simplicity is lost, these solutions guarantee very fast response together with limited tracking error. Thus, constant frequency hysteresis controls are well suited for high performance high-speed applications.

ADAPTIVE CONTROL:

An adaptive control system is a system which adjusts automatically on-line the parameters of its controller, so as to maintain a satisfactory level of performance when the parameters of the system under control are unknown and/or time varying.

Adaptive Control techniques can be generally classified as

- Self-tuning control
- MRAC
- Sliding mode or variable structural control
- Expert system control
- Fuzzy Control
- Neural Control

Adaptive Hysteresis Current Controller:

An adaptive hysteresis-band current control PWM technique can be programmed as a function of the active filter and supply parameters to minimize the influence of current distortions on a modulated waveform.

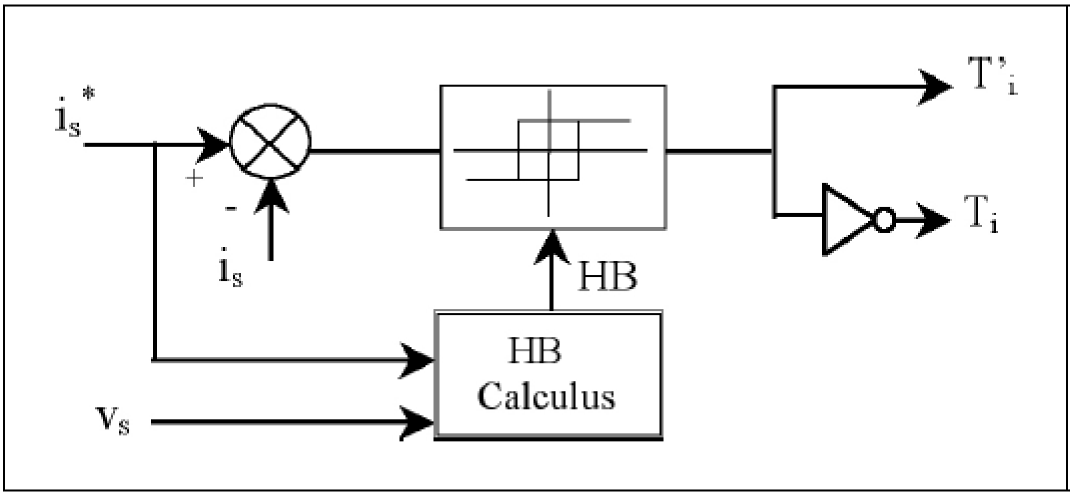


Fig4.3 Simplified model for an adaptive hysteresis band current controller

4.3 CONCLUSION

All the techniques, hysteresis control, deadbeat control, and linear rotating frame control were considered, including the latest improvements brought by their industrial application. The improvements in the control techniques result in rather satisfactory performance levels for all three controllers. However, the results of the comparison show a certain superiority of the hysteresis control. Indeed, the performance of this control strategy is almost unaffected by the variation in the firing angle and, on the basis of the performance indices considered in the paper, i.e., harmonic content, THD, and rms of the current error, turns out to be better than the other techniques. The deadbeat controller, which has the advantage of being suitable for a fully digital implementation, is limited in its performance by the inherent calculation delay. Instead, the linear control‘s bandwidth limitation turns into a not completely satisfactory quality of compensation, especially in correspondence of high di/dt in the current reference.

The substantial increase in the use of solid-state power control results in harmonic pollution above the tolerable limits. Utilities are finding it difficult to maintain the power quality at the consumer end, and consumers are paying the penalties indirectly in the form of increased plant downtimes, etc. At present, APF technology is well developed, and many manufacturers are fabricating APF's with large capacities. The utilities in the long run will induce the consumers with nonlinear loads to use the APF's for maintaining the power quality at acceptable levels. A large number of APF configurations are available to compensate harmonic current, reactive power, neutral current, unbalance current, and harmonics. The consumer can select the APF with the required features.

CHAPTER 5

COMPARATIVE STUDY OF PI , FUZZY AND NEURAL NETWORK CONTROLLERS

5.1 Introduction

The controller is the heart of the primary component of the Active power line conditioners (APLC) system. Conventional PI Controllers are used to extract the fundamental component of the load current thus facilitating reduction of harmonics and simultaneously controlling dc-side capacitor voltage of the voltage source inverter. Recently the terms Expert system(ES), Fuzzy logic(FL), artificial neural network(ANN), and genetic algorithm(GA) belong to an area called artificial intelligence(AI). The area of AI has penetrated deeply into electrical engineering, and their applications in power electronics and motion control appears very promising. controllers are used in power electronic system, drive applications and active power filters.

5.2 PI Controllers

The below fig shows the block diagram of PI Controller. The DC Side Capacitor voltage is sensed and compared with a reference voltage. This error e= $V_{dc,ref}$ – Vdc is used as the input for PI Controller. The error signal is passed through Butterworth design based Low Pass Filter(LPF). The LPF filter has cutoff frequency at 50Hz that can suppress the higher order components and allow only fundamental components. The transfer function of the PI Controller is represented as

$$H(s)= K_p + K_I/S \text{ ....(1)}$$

Where Kp is the proportional constant that determines the dynamic response of the DC-side voltage control and K_I is the integration constant that determines its settling time. The proportional integral controller is eliminating study state error in the DC- side voltage.

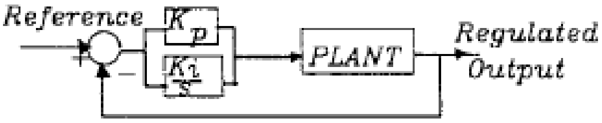


Fig.5.1 Closed loop control using PI controller

5.2.1 Advantages and Disadvantages Of PI Controllers:

i) The integral term in a PI controller causes the steady-state error to reduce to zero, which is not the case for proportional-only control in general.

ii) The lack of derivative action may make the system more steady in the steady state in the case of noisy data. This is because derivative action is more sensitive to higher-frequency terms in the inputs.

iii) Without derivative action, a PI-controlled system is less responsive to real (non-noise) and relatively fast alterations in state and so the system will be slower to reach set point and slower to respond to perturbations than a well-tuned PID system may be.

5.3 Fuzzy Logic Controllers:

Based on the nature of fuzzy human thinking, Lotfi Zadeh, a computer scientist at the University of California, Berkeley, originated the “fuzzy logic,” or fuzzy set theory, in 1965.The general methodology of reasoning in FL and ES by “IF…….THEN…..” statements or rules is the same; it is often called “ fuzzy expert system.”

The design of a conventional control system is normally based on the mathematical model of a plant. If an accurate mathematical model is available with known parameters, it can be analyzed. Fuzzy control, on the other hand, does not strictly need any mathematical model of the plant. Fuzzy control is basically an adaptive and nonlinear control, which gives robust performance for a linear or nonlinear plant with parameter variation. In fact, fuzzy control is possibly the best adaptive control among all other techniques.

5.3.1 REVIEW OF FUZZY LOGIC CONTROL:

Fuzzy logic unlike Boolean or crisp logic, deal with problems that have vagueness, uncertainty or imprecision and uses membership functions with values varying between 0 and 1. Fuzzy logic uses fuzzy set theory, in which a variable is a member of one or more sets, with a specified degree of membership. Fuzzy logic allow us to emulate the human reasoning process in computers, quantify imprecise information, make decision based on vague and in complete date, yet by applying a “defuzziciation” process, arrive at definite conclusions. The block diagram representation of a fuzzy logic controller(FLC) is shown in below Fig.5.2 [20]

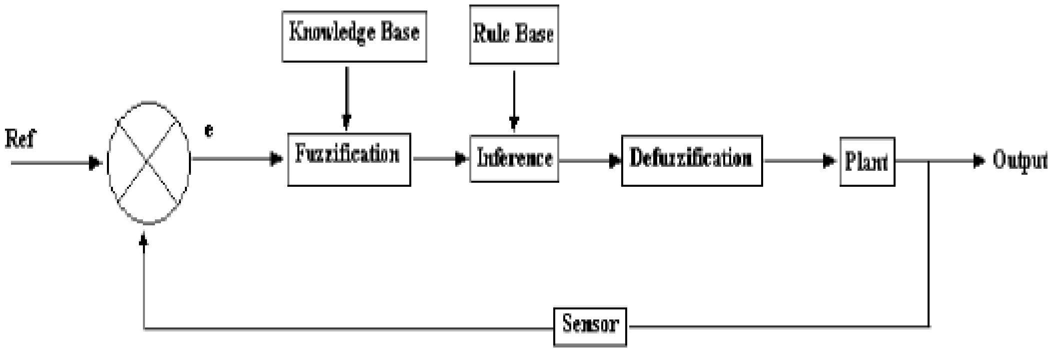


Fig 5.2 : Block diagram of FLC

The FLC mainly consists of three blocks

- Fuzzification
- Inference
- Defuzzification

The details of the above process are given below.

Fuzzification:

The fuzzy logic controller requires that each input/output variable which define the control surface be expressed in fuzzy set notations using linguistic levels. The linguistic values of each input and output variables divide its universe of discourse into adjacent intervals to form the membership functions. The member value denotes the extent to which a variable belong to a particular level. The process of converting input/output variable to linguistic levels is termed as fuzzification.

Inference:

The behaviour of the control surface which relates the input and output variables of the system is governed by a set of rules. A typical rule would be

If x is A Then y is B

When a set of input variables are read each of the rule that has any degree of truth in its premise is fired and contributes to the forming of the control surface by approximately modifying it. When all the rules are fired, the resulting control surface is expressed as a fuzzy set to represent the constraints output. This process is termed as inference.

Defuzzification:

Defuzzification is the process of conversion of fuzzy quantity into crisp quantity. There are several methods available for defuzzification. The most prevalent one is centroid method, which utilizes the following formula:

$$\frac{\int(\mu(x).x}{\int \mu(x)dx} \ldots\ldots\ldots\ldots(2)$$

where μ is the membership degree of output x.

Data Base: The Database stores the definition of the membership function required by fuzzifier and defuzzifier. Storage format is a compromise between available memory and MIPS of the digital controller chip.

Rulebase : The Rulebase stores the linguistic control rules required by rule evaluator (decision making logic). Fig 5 shows the rule table used in this paper.

5.3.2 Applications of Fuzzy Logic Controller:

Fuzzy logic has been widely applied in power electronic systems. Applications include speed control of dc and ac drives, feedback control of converter, off-line P-I and P-I-D tuning, nonlinearity compensation, on-line and off-line diagnostics, modelling, parameter estimation, performance optimization of drive systems based on on-line search, estimation for distorted waves, and so on.

5.4 Neural Network Controller:

The artificial neural network(ANN), often called the neural network, is the most generic form of AI for emulating the human thinking process compared to the rule-based ES and FL.

5.4.1 Neural Network Structure:

Neural networks are models of biological neural structures. The starting point for most neural networks is a model neuron, as in Figure 2. This neuron consists of multiple inputs and a single output. Each input is modified by a *weight*, which multiplies with the input value. The neuron will combine these weighted inputs and, with reference to a threshold value and activation function, use these to determine its output. This behavior follows closely our understanding of how real neurons work.

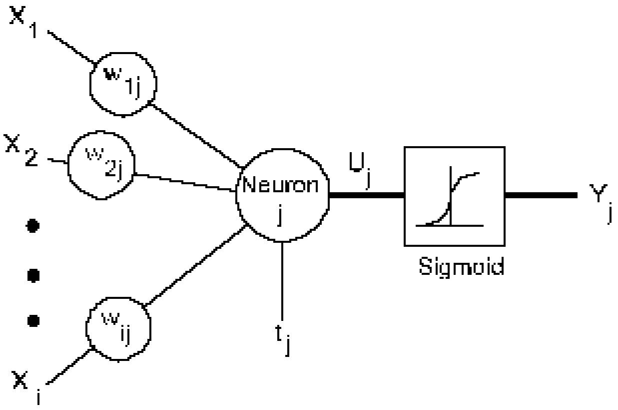


Fig. 5.3: A Model Neuron

While there is a fair understanding of how an individual neuron works, there is still a great deal of research and mostly conjecture regarding the way neurons organize themselves and the mechanisms used by arrays of neurons to adapt their behavior to external stimuli. There are a large number of experimental neural network structures currently in use reflecting this state of continuing research.

In our case, we will only describe the structure, mathematics and behavior of that structure known as the *back propagation network*. This is the most prevalent and generalized neural network currently in use.

To build a back propagation network, proceed in the following fashion. First, take a number of neurons and array them to form a *layer*. A layer has all its inputs connected to either a preceding layer or the inputs from the external world, but not both within the same layer.

A layer has all its outputs connected to either a succeeding layer or the outputs to the external world, but not both within the same layer.

Next, multiple layers are then arrayed one succeeding the other so that there is an input layer, multiple intermediate layers and finally an output layer, as in Figure 3. Intermediate layers, that is those that have no inputs or outputs to the external world, are called >*hidden layers*.

Back propagation neural networks are usually *fully connected*. This means that each neuron is connected to every output from the preceding layer or one input from the external world if the neuron is in the first layer and, correspondingly, each neuron has its output connected to every neuron in the succeeding layer.

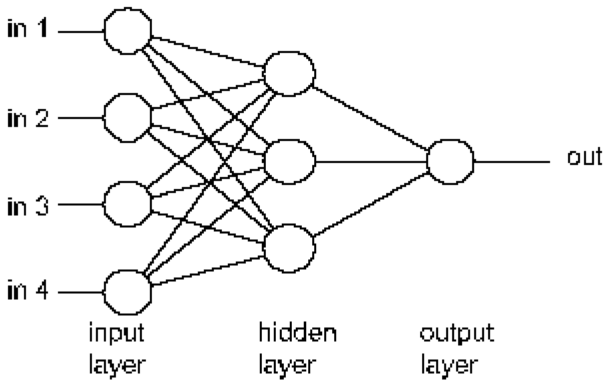


Fig. 5.4. Back propagation Network

Generally, the input layer is considered a distributor of the signals from the external world. Hidden layers are considered to be categorizers or feature detectors of such signals.

$$Y_j = F_{th}(U_j + t_j)$$

The output layer is considered a collector of the features detected and producer of the response. While this view of the neural network may be helpful in conceptualizing the functions of the layers, you should not take this model too literally as the functions described may not be so specific or localized. With this picture of how a neural network is constructed, we can now proceed to describe the operation of the network in a meaningful fashion.

5.4.2 Neural Network Operation:

The output of each neuron is a function of its inputs. In particular, the output of the ***j***th neuron in any layer is described by two sets of equations.

For every neuron, ***j***, in a layer, each of the ***i*** inputs, X_i, to that layer is multiplied by a previously established weight, w_{ij}. These are all summed together, resulting in the internal value of this operation, U_j. This value is then biased by a previously established threshold value, t_j, and sent through an activation function, F_{th}. This activation function is usually the sigmoid function, which has an input to output mapping as shown in Figure 4. The resulting output, Y_j, is an input to the next layer or it is a response of the neural network if it is the last layer. Neuralyst allows other threshold functions to be used in place of the sigmoid described here.

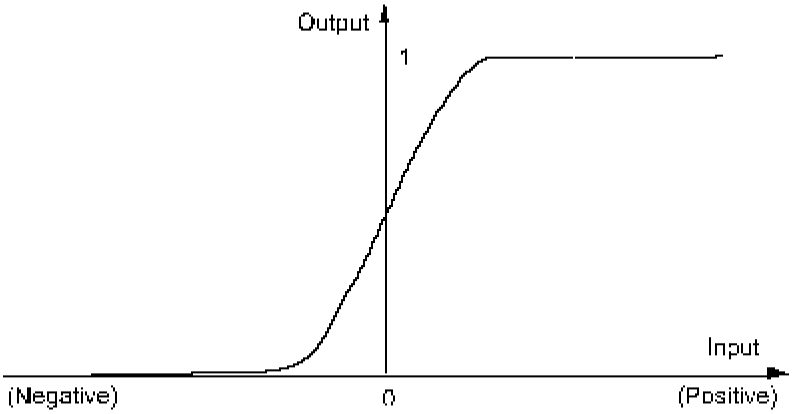


Fig. 5.5. Representation of Sigmoid Function

From these a predetermined set of weights, a predetermined set of threshold values and a description of the network structure (that is the number of layers and the number of neurons in each layer), it is possible to compute the response of the neural network to any set of inputs. And this is just how Neuralyst goes about producing the response. But how does it learn?

5.4.3 Neural Network Learning:

Learning in a neural network is called *training*. Like training in athletics, training in a neural network requires a coach, someone that describes to the neural network what it should have produced as a response. From the difference between the desired response and the actual response, the *error* is determined and a portion of it is propagated backward through the network. At each neuron in the network the error is used to adjust the weights and threshold values of the neuron, so that the next time, the error in the network response will be less for the same inputs.

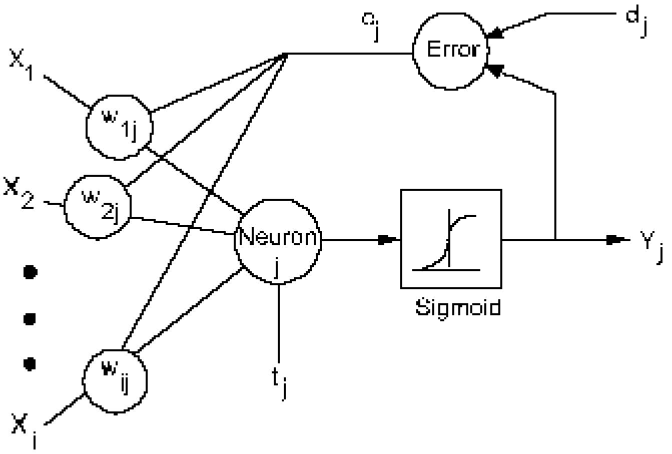


Fig. 5.6 Neuron Weight Adjustment

This corrective procedure is called *back propagation* (hence the name of the neural network) and it is applied continuously and repetitively for each set of inputs and corresponding set of outputs produced in response to the inputs. This procedure continues so long as the individual or total errors in the responses exceed a specified level or until there are no measurable errors. At this point, the neural network has learned the training material and you can stop the training process and use the neural network to produce responses to new input data.

5.4.4 Applications of Neural Network Controllers:

Neural Networks have been applied for various control, identification, and estimation applications in power electronics and drives. Some of these applications can be summarized as follows:

- Single or multi-dimensional look-up table functions
- Converter PWM
- Neural adaptive P-I driver controller
- Delay less filtering
- Vector rotation and inverse rotation in vector control
- Drive MRAC
- Drive feedback signal estimation
- On-line diagnostics
- Estimation for distorted waves
- FFT signature analysis of waves

5.5 COMPARASION

The controllers for PI, FLC, and Neural Network were compared. The design of FLC is primarily based on a trial and error procedure. The triangular membership was considered because of its simplicity of implementation and because less computational intensity is required. The number of linguistic variables and the base width of linguistic variables have some effect on the response time and magnitude of ripple in the output voltage. However, they don‘t seriously affect the response as the change of gains in a PI controller does. In the design for Neural Network Controller weights of the inputs to be adjusted through proper training of the neural network which gives optimum results. In the design of the PI-controller, the gain selection is crucial. A set of gains can be ideal for one type of disturbance but not for another type of disturbance. The gains were selected to provide a performance compromise for supply voltage disturbance and load disturbance.

For supply disturbance, FLC and Neural Network respond in a highly damped manner with a small overshoot whereas PI responds in an under damped manner with very high overshoot.

5.6 CONCLUSION

The study of fuzzy logic control, PI control, and Neural Network Controller suggest that FLC, Neural Network Controller performs satisfactorily in regulating the output during external disturbances. PI shows under damped response during disturbances due to off-tuned gain constants. From the study of FLC and Neural Network controllers, it can be understand that they are intentionally adaptive in nature. Hence these two controllers are . seems to be a viable solutions for application in power electronic systems.

CHAPTER 6

SYSTEM STUDY

6.1 Introduction

The use of solid state power conversion is rapidly increasing in adjustable speed drives (ASDs), power supplies etc. These solid state converters inject harmonics and cause low power factor of ac mains. The system uses an insulated gate bipolar transistor (IGBT) based VSC as an APF and a three-phase diode bridge rectifier fed R-L load as a nonlinear load. Most of active power filters are based on sensing harmonics and reactive volt-ampere requirements of the nonlinear load, and require complex control. In this scheme instantaneous pq theory is proposed for generation of compensating current signals by sensing the load currents[1]. Recently, fuzzy logic controllers (FLCs) have generated a good deal of interest especially in control applications as these FLCs can overcome the setbacks of PI controllers in terms of imprecise inputs, robustness, nonlinearity, parameter variations and mathematical modeling’s.

In this work Adaptive hysteresis based fuzzy logic controlled shunt active power filter for the mitigation of source current harmonics and reactive power compensation of a nonlinear load. The DC capacitor voltage is regulated to estimate the reference current template [21].

6.2 BASIC COMPENSATION PRINCIPLE

Figure 6.1 represents the shunt active power filter based on Voltage Source Inverter(VSI) structure is an attractive solution to harmonic current problems. The shunt active filter is a pulse width modulated(PWM) current controlled - voltage source inverter(VSI) that is connected in parallel with the load. It has the capability to inject harmonic current into the AC system with the same amplitude but opposite phase than that of the load [1].

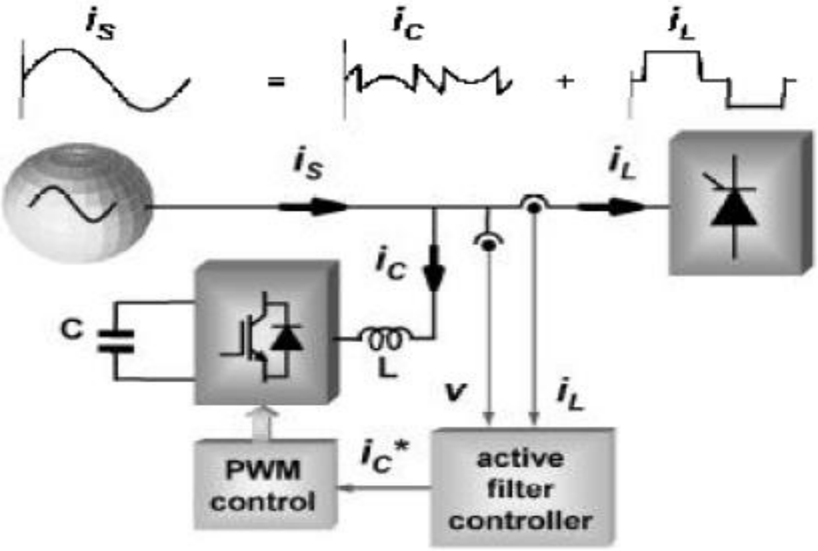


Fig 6.1 : Basic Configuration of a shunt active filter.

Shunt active filters generally consist of two distinct main blocks.

1.PWM Converter (Power Processing)
2. The active filter controller (signal processing)

The PWM Converter is responsible for power processing in synthesizing the compensating current that should be drawn from the power system. The active filter controller is responsible for signal processing in determining in real time the instantaneous compensating current references, which are continuously passed to the PWM converter. Figure 6.1 shows the basic configuration of shunt active filter for harmonic current compensation of a specific load. It consists of a voltage-fed converter with a PWM current controller and an active filter controller that realizes an almost instantaneous control algorithm. The shunt active filter controller works in a closed-loop manner, continuously sensing the load current i_L , and calculating the instantaneous values of the compensating current i_C^* for the PWM converter.

6.2.1 Role of DC side capacitor

Another important task in the active filter design is the maintenance of constant DC voltage across the capacitor connected to the inverter[20]. This is necessary because there is energy loss due to conduction and switching power losses associated with the diodes and IGBTs of the inverter in APF, which tend to reduce the value of voltage across the DC capacitor. Generally PI Controller is used to control the DC bus voltage. The PI controller based approach requires precise linear mathematical model which is difficult to obtain. Also, it fails to perform satisfactorily under parameter variations, non-linearity, and load disturbances. In this work a fuzzy logic controller and Neural Network controller are proposed for D.C Voltage controller.

The DC side capacitor serves two main purposes:

1. It maintains a DC voltage with small ripple in steady state, and
2. It serves as an energy storage element to supply the real power difference between load and source during the transient period.

In steady state the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate for the losses in the active filter. Thus DC capacitor voltage can be maintained at a reference value.

However, when the load condition changes the real power balance between the mains and the load will be disturbed. This real power difference is to be compensated by the DC capacitor.

This changes the DC capacitor voltage away from the reference voltage. In order to keep satisfactory operation of the active filter, the peak value of the reference source current must be adjusted to proportionally change the real power drawn from the source. This real power charged/discharged by the capacitor compensates for the real power consumed by the load. If the DC capacitor voltage is recovered and attains the reference voltage, the real power supplied by the source is supposed to be equal to that consumed by the load again.

Thus, In this way the peak value of the reference source current can be obtained by regulating the average voltage of the DC capacitor. A smaller DC capacitor voltage than the reference voltage means that the real power supplied by the source is not enough to supply the load demand. Therefore, the source current (i.e. the real power drawn from the source) needs to be increased, while a larger DC capacitor voltage than the reference voltage tries to decrease the reference source current. This change in capacitor voltage has been verified from the simulation results.

6.2.2. Generation of Compensating reference currents

In this work compensating reference currents are derived based on instantaneous p-q theory. The p-q theory defines a set of instantaneous powers in the time domain[1]. Since no restrictions are imposed on voltage and current behaviors, it is applicable to three phase systems with or without neutral conductors, as well as to generic voltage and current waveforms. Thus, is it valid not only in steady states, but also during transient states. The p-q theory deals with all the three phase systems at the same time, as a unity system. The p-q theory provides a very efficient and flexible basis for designing control strategies and implementing them in the form of controllers for power conditioners based on power electronic devices.

The instantaneous p-q theory [1] is based on "α-β" transformation of voltage and current signals to derive compensating signals. From instantaneous active and reactive powers, harmonic active and reactive powers are extracted using low-pass filters. From harmonic active and reactive powers, using reverse "α-β" transformation, compensating commands in terms of currents are derived. The details of p-q theory is given in below. Basically, the three phase instantaneous voltages, Va , Vb , Vc and currents Ia , Ib , Ic are expressed as instantaneous space vectors on the a-b-c coordinates with each component 2π/3apart from each other. However, the three phase voltages and currents are transformed into orthogonal coordinates, α-β coordinates. This transformation allows the compliance with the right hand rule for real and reactive power calculation. Fig.6.2 shows the transformations of the three phase voltages and currents vectors in a-b-c coordinates into orthogonal coordinates, α-β coordinates.

The instantaneous current and voltage space vector are expressed in terms of instantaneous voltages and currents as,

$$V = [\ V_a\ V_b\ V_c\ ]^T \qquad \text{………(1)}$$

$$I = [\ I_a\ I_b\ I_c\ ]^T \qquad \text{………(2)}$$

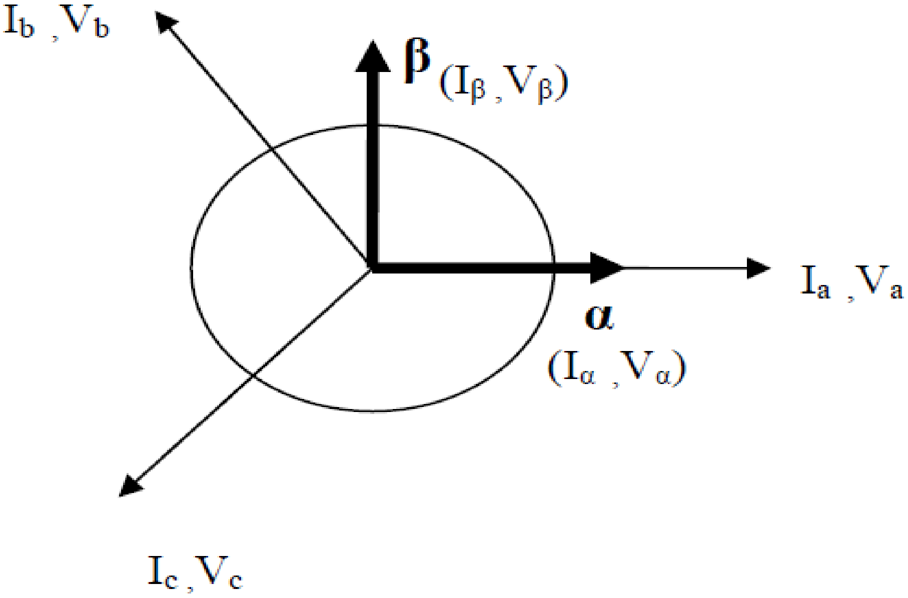


Fig. 6.2: Schematic Representation of a-b-c to α-β Transformation

Instantaneous Voltage and Currents on the a-b-c coordinates can be transformed into the quadrature α, β coordinates by Clarke transformation as follows.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \qquad \text{……………………(3)}$$

$$\begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} \qquad \text{……………………(4)}$$

An instantaneous voltage vector is defined from the instantaneous α- and β-voltage components, that is

$$\mathbf{e} = V_\alpha + j\,V_\beta \qquad \text{……………(5)}$$

Similarly the instantaneous current vector is defined as,

$$\mathbf{i} = I_\alpha + j\,I_\beta \qquad \text{……………(6)}$$

The above instantaneous vectors can be represented in complex plane, where the real axis is the α-axis and the imaginary axis is the β-axis of the Clarke transformation. It should be noted that the vectors defined above are functions of time, because they consists of the Clarke components of the instantaneous phase voltages and line currents in three phase system.

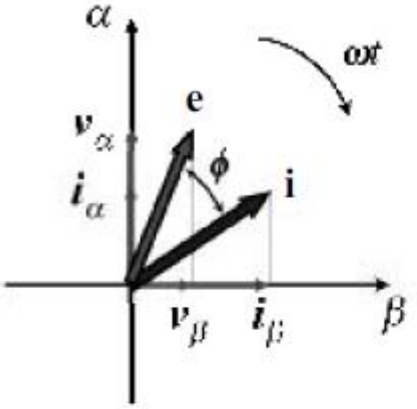


Fig. 6.3: Vector representation of voltage and currents on the α-β reference frames

A new definition of instantaneous complex power is possible, using the instantaneous vectors of voltage and current. The instantaneous complex power **s** is defined as the product of the voltage vector **e** and the conjugate of the current vector **i*,** given in the form of complex numbers:

$$\begin{aligned} \mathbf{s} = \mathbf{e} \cdot \mathbf{i}^* &= (V_\alpha + j V_\beta)(I_\alpha - j I_\beta) \\ &= (V_\alpha I_\alpha + V_\beta I_\beta) + j (V_\beta I_\alpha - V_\alpha I_\beta) \\ &= p + j q \end{aligned}$$

Since in a balanced three-phase three wire system neutral current is zero, the zero sequence current does not exist. The power components p and q are related to the same α-β voltages and currents, and can be written together as given below,

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} \quad \ldots\ldots\ldots\ldots\ldots\ldots(7)$$

Where p is the instantaneous real power and q is the instantaneous imaginary power include AC and DC values and can be expressed as follows.

$$p = \bar{p} + \tilde{p}$$

$$q = \bar{q} + \tilde{q}$$

The calculated real power of the load p can be separated into its average($\bar{p}$) and oscillating($\tilde{p}$) parts. Likewise, the load imaginary power q can be separated into its average($\bar{q}$) and oscillating ($\tilde{q}$) parts.

Then, undesired portions of real and imaginary powers of the load that should be compensated are selected. The powers to be compensated are represented by $-p_c^*$ and $-q_c^*$ in the controller as shown in Fig.6.4

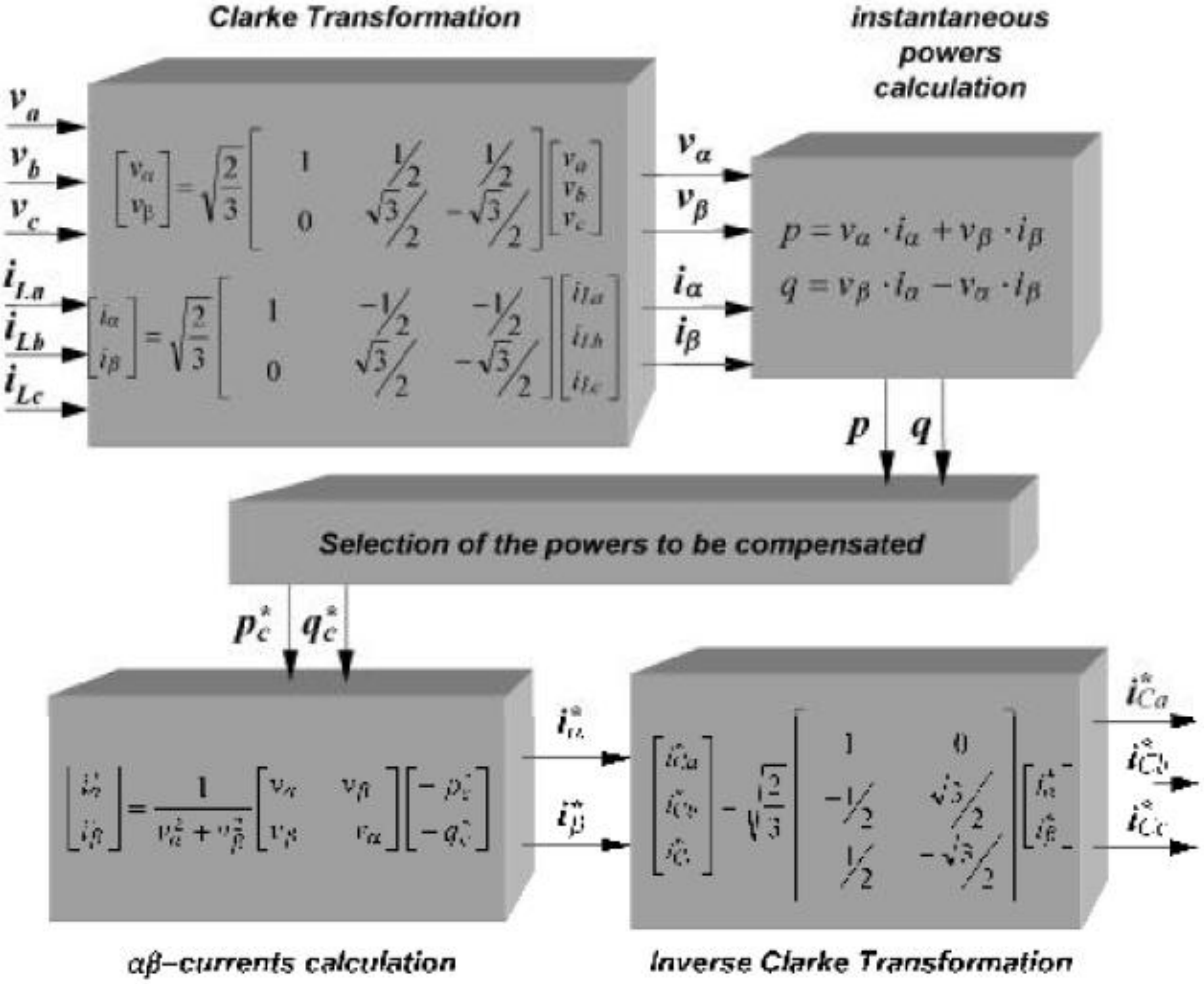


Fig. 6.4 : Control method for shunt current compensation based on p-q Theory.

The reason for including minus signals in the compensating powers is to emphasize that the compensator should draw a compensating current that produces exactly the inverse of the undesirable powers drawn by the nonlinear load. Then the inverse transformation from αβ to abc is applied to calculate the instantaneous values of the three phase compensating current references i_{ca}^*, i_{cb}^*,and i_{cc}^*.

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{(V_\alpha^2 + V_\beta^2)} \begin{bmatrix} V_\alpha & V_\beta \\ V_\beta & -V_\alpha \end{bmatrix} \begin{bmatrix} -p_c^* \\ -q_c^* \end{bmatrix} \ldots\ldots\ldots\ldots(8)$$

In order to obtain the reference compensation currents in the a-b-c coordinates the inverse of the transformation given in expression (9) is applied.

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \ldots\ldots\ldots\ldots\ldots(9)$$

6.3 Modeling of the System

The complete active filter system is composed mainly of

1. A three-phase source,
2. A three-phase bridge diode rectifier with R-L load is considered as a nonlinear load,
3. A voltage source PWM converter, and
4. A fuzzy controller for DC Voltage control.

The block diagram representation of the proposed control strategy for the shunt active filter is shown in Fig 6.5. The control strategy is implemented in three steps. In the first step, the required voltage and current signals are sensed to gather accurate system information. In the second step, reference compensating currents are derived based on instantaneous p-q theory. In the third step, the gating signals for the solid-state devices are generated using hysteresis-based current control method. The source is already modeled as ideal voltage source and remaining elements has been modeled in the following sessions.

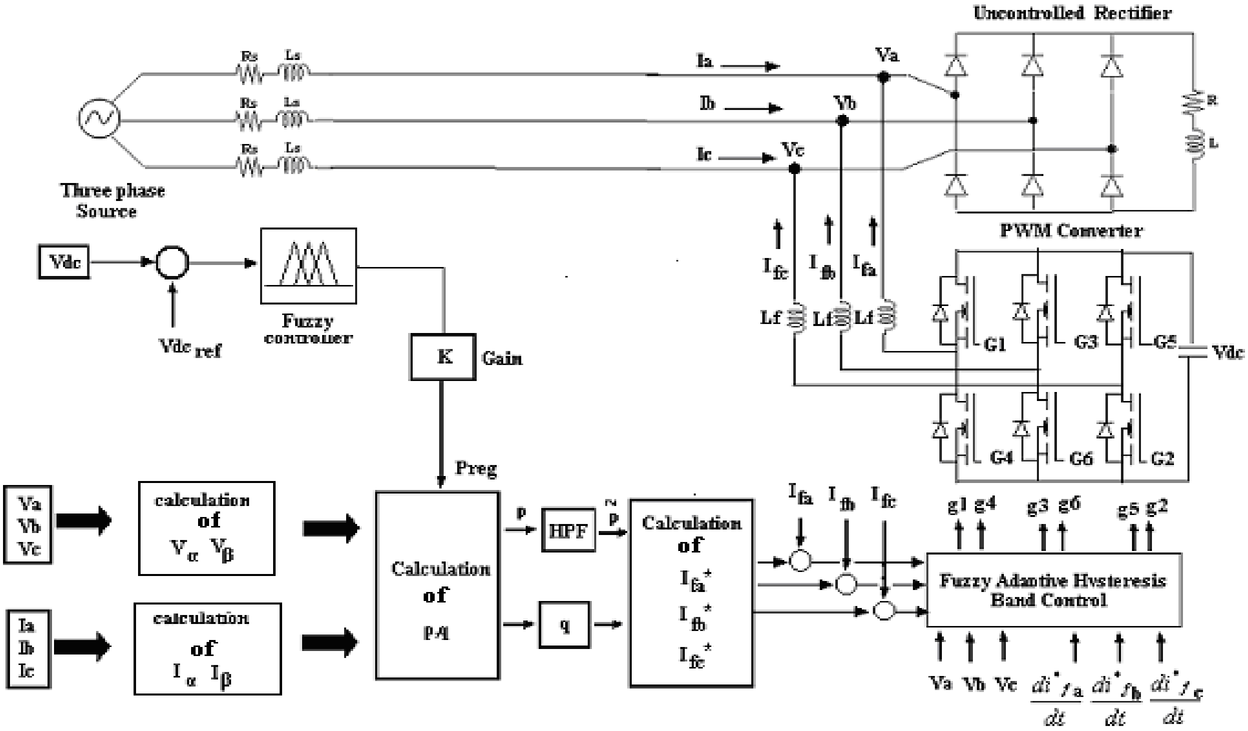


Fig.6.5: Schematic Diagram of Closed Loop Adaptive Hysteresis based Fuzzy Logic Controlled Shunt APF

6.3.1 Fuzzy Logic based DC Voltage Control:

To design the FLC, variables which can represent the dynamic performance of the plant to be controlled should be chosen as the inputs to the controller[20]. It is common to use the output error and the rate of error (de/dt) as controller inputs. In the case of the fuzzy logic based DC voltage control, the capacitor voltage deviation and its derivative are considered as the inputs of the FLC and the real power (Preg) requirement for the voltage regulation is taken as the output of the FLC. The input and output variables are converted into linguistic variables. In this case, seven fuzzy subsets, NL(Negative large), NM(Negative medium), NS(Negative small), ZE (Zero), PS(Positive Small), PM(Positive Medium) and PL(Positive Large) have been chosen.

Membership functions used for the input and output variables used here are shown in Fig.6.6. As both inputs have seven subsets, a fuzzy rule base formulated for the present application is given in table 6.1.

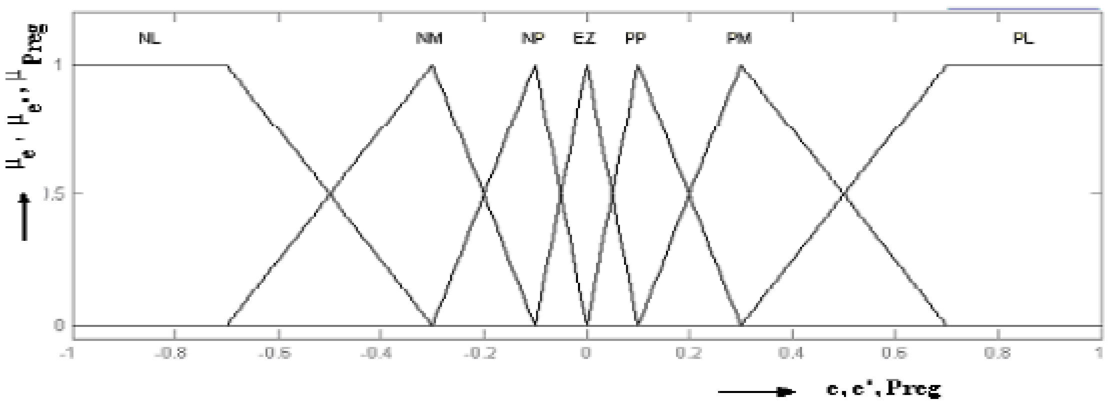


Fig6.6: Membership function for the input and output variable

Table 6.1 Control rule table

e de	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	NL	NL	NL	NL	NM	NS	ZE
NM	NL	NL	NL	NM	NS	ZE	PS
NS	NL	NL	NM	NS	ZE	PS	PM
ZE	NL	NM	NS	ZE	PS	PM	PL
PS	NM	NS	ZE	PS	PM	PL	PL
PM	NS	ZE	PS	PM	PL	PL	PL
PL	NL	NM	NS	ZE	PS	PM	PL

6.3.2 Neural Network based DC Voltage Control:

The control objective of the NN is to provide the wanted proper gating patterns of the PWM inverter, leading to adequate tracking of the APF reference phase currents and constant DC voltage The architecture of proposed neural network has two layer (input and output) network having n-inputs and a single output. The basic blocks of this network are input signal delay vector, Weight matrix and bias. The input output relationship is expressed as:

$$y = \sum W_n * i_n + b \quad \ldots\ldots\ldots.(10)$$

Where ‘b’ is the bias, ‘W’ is weight, and ‘i’ is the input to the NN. The input to the ANN system is the difference of reference DC link voltage and actual voltage sensed across the capacitor of VSI. The weight matrices and the bias vectors are updated during the training process. The NN has been trained by a resilient back-propagation algorithm[28]. The mean square error between desired output and the actual output was reduced by repetitive training.

.

6.3.3 Adaptive Hysteresis current control:

The switching signals for the voltage source inverter are going to be generated by the adaptive hysteresis band current controller. The band width of the hysteresis current controller is given by [22],[23].

$$HB_j = \frac{V_{dc}}{6 f_m L_f}[1 - \frac{9L_f^2}{V_{dc}}(\frac{v_s(t)}{L_f} + \frac{di_{fj}^*}{dt})^2] \text{ , j=1,2,3...........(10)}$$

Where f_m is the modulation frequency, i_{fa}* is the source reference current, $\frac{di_{fa}^*}{dt}$ represents its slope, L_f is the decoupling inductance of the active power filter, V_{dc} is the DC bus voltage and $v_s(t)$ is supply voltage. The adaptive hysteresis band current controller changes the hysteresis bandwidth according to instantaneous compensation current variation $\frac{di_{fa}^*}{dt}$ and V_{dc} voltage to minimize the influence of current distortion on modulated waveform.

The current controllers of the three phases are designed to operate independently. Each current controller determines the switching signals to the inverter. The switching logic for phase A is formulated as below[24]:

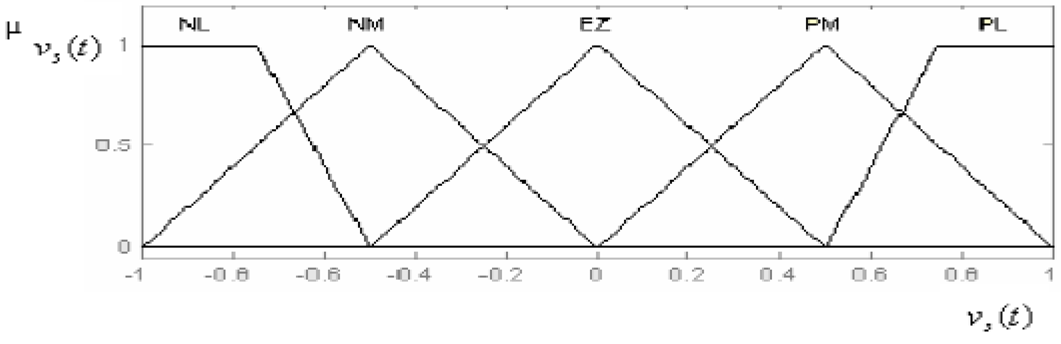
If $i_{fa} <$ (i_{fa}* - HB) upper switch(G1) is OFF and lower switch (G4) is ON.

If $i_{fa} >$ (i_{fa}* + HB) upper switch (G1) is ON and lower switch (G4) is OFF.

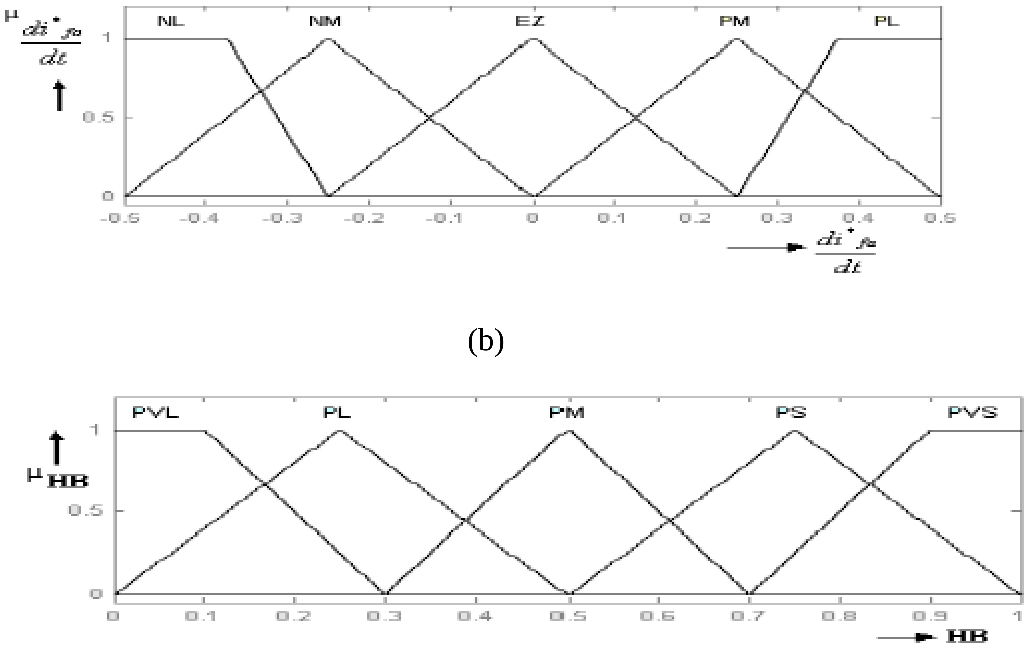
In the same fashion, the switching of phases B and C devices are derived.

6.3.4 Fuzzy Adaptive Hysteresis current control:

From equation (10) , it is noted that the hysteresis band width is the function of $\frac{di_{fa}^*}{dt}$ and $v_s(t)$. Hence these variables are selected as input variables to the fuzzy controller, and the hysteresis band width(HB) is the output. Five linguistic variables are assigned to the input and output variables in this case. The member ship functions of input and output variables are shown in Fig . The fuzzy rule table with 25 rules is given in Table 6.2.



(a)



(b)

(c)

Fig. 6.7: Membership functions for the input variables (a) V_s (t) , (b) $\frac{di^*_{fa}}{dt}$ and (c) Output variable HB.

Table 6.2 Control rule table

$\frac{di^*_{fa}}{dt}$ / $v_s(t)$	**NL**	**NM**	**EZ**	**PM**	**PL**
NL	PS	PM	PM	PM	PS
NM	PS	PM	PL	PM	PS
EZ	PVS	PM	PVL	PM	PVL
PM	PS	PM	PL	PM	PS
PL	PS	PM	PM	PM	PS

In this method the switching frequency is kept constant and the current error is appreciably reduced ensuring better global stability and insensitivity to parameter variation.

CHAPTER 7

SIMULATIONS AND RESULTS

7.1 System Parameters

This section presents the details of the simulation carried out to demonstrate the effectiveness of the proposed control strategy for the active filter to reduce the harmonics. Following are the system parameters considered for the study of APF for both PI, Fuzzy controller, Neural Network controller. In case of PI the gains chosen are k_p=0.05 and k_i= 0.4. The load chosen is of R_l = 70 Ω, L_l= 3mH, modulation frequency is 10KHz. The other system parameters are given in Table (7.1).

Table 7.1 System Parameters

System Parameters	**Values**
Supply phase to phase voltage, frequency	415V(rms), 50Hz
Supply line parameters	R_s=1Ω, L_s=3mH
Filter impedance(R_f , L_f)	0.5Ω; 3mH
Inverter DC bus capacitor	1mF
Reference DC link voltage $v_{dc,ref}$	700V
Hysteresis Band Limit	0.5A
Sampling Time	$2e^{-6}$ sec

7.2 Source Current THD Without Filter:

The three phase line current in the absence of the filter is shown in Fig7.1(a). And Fig 7.1(b) shows the harmonic spectrum of the distorted waveform. The total harmonic Distortion(THD) of the distorted line current is 26.44%.

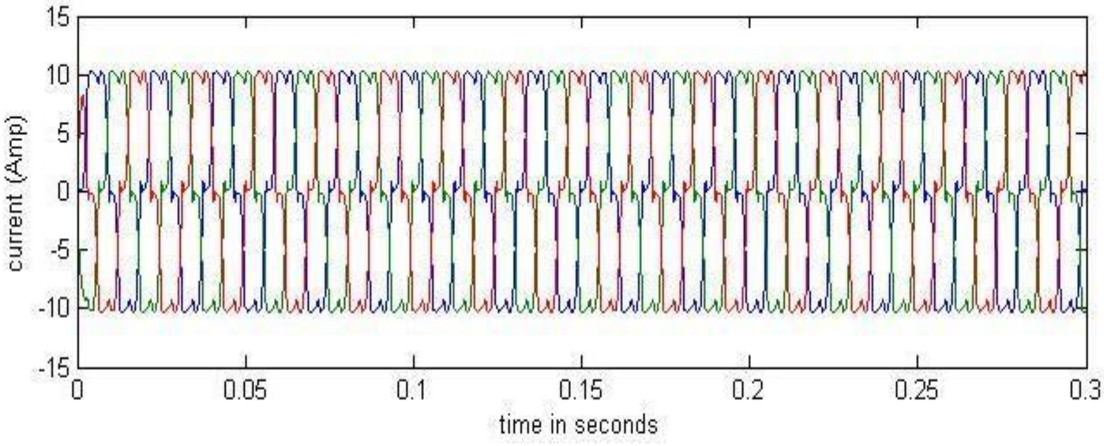


Fig. 7.1(a) Distorted three phase line currents

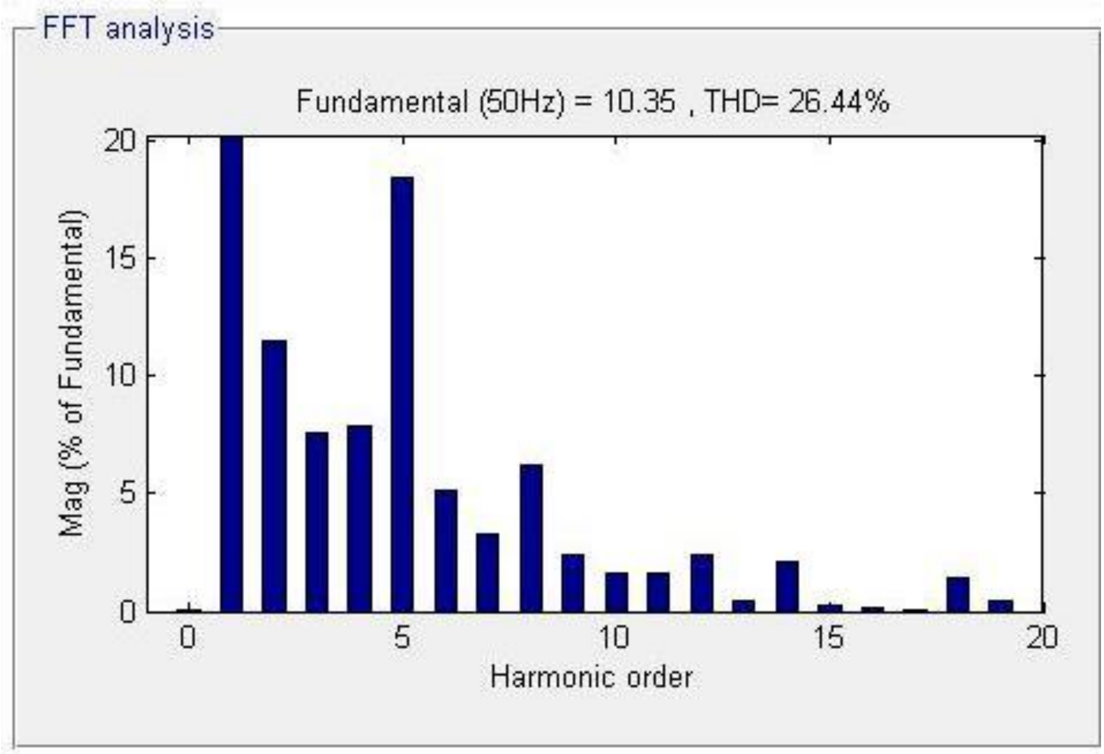


Fig.7.1(b) Harmonic Spectrum of the line current

7.3 Performance with PI Voltage Controller and Fixed Hysteresis band current Controller:

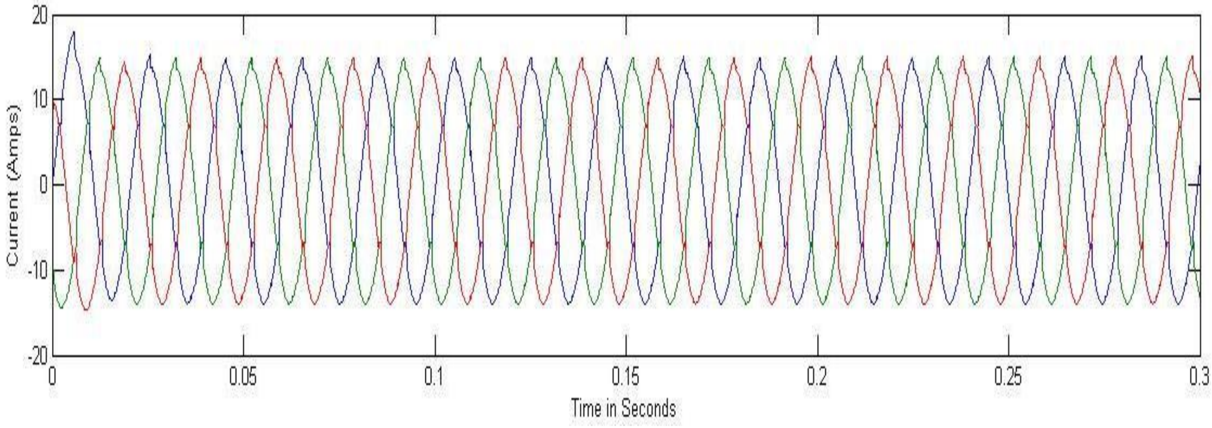


Fig 7.2(a) Source Current

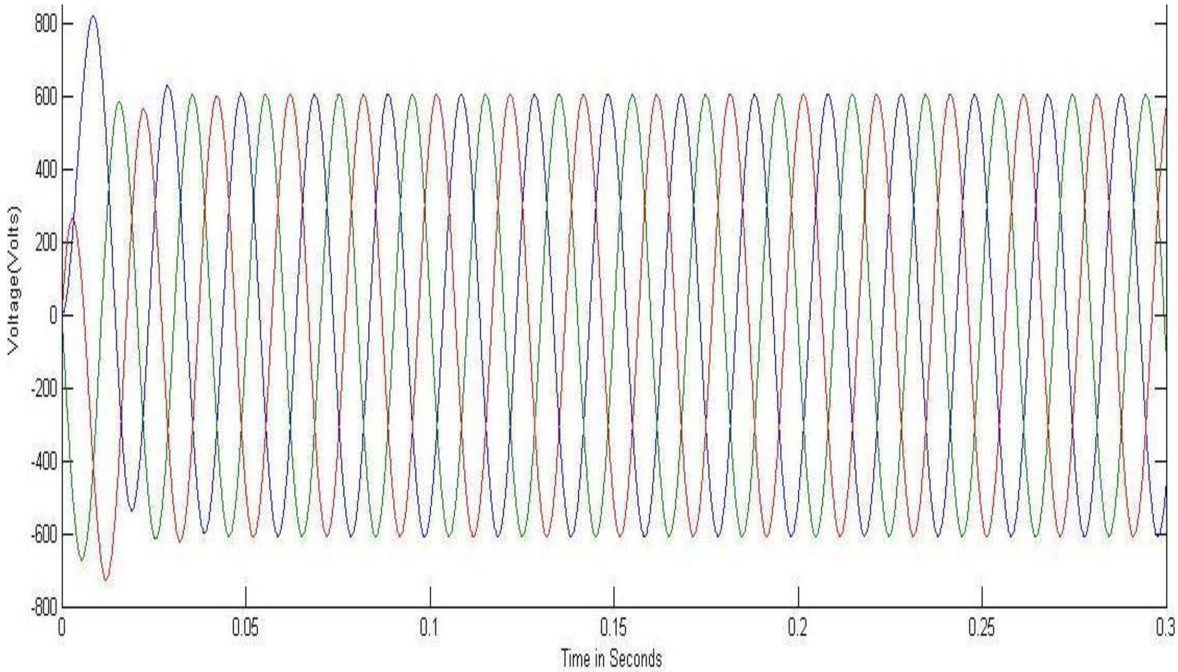


Fig.7.2(b) Source Voltage

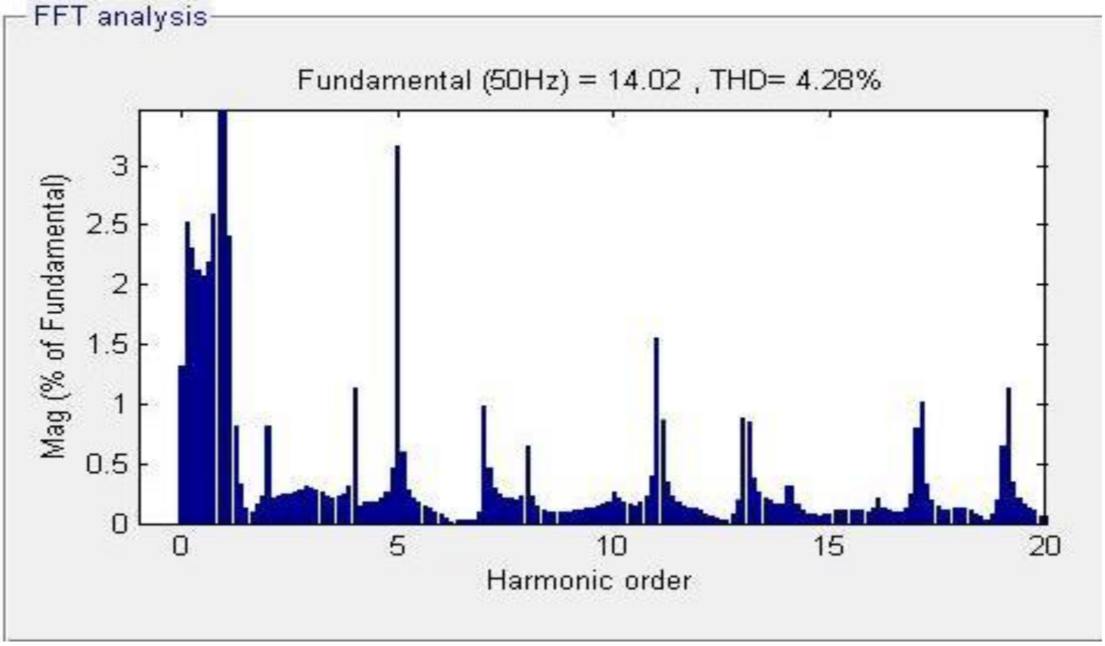


Fig. 7.2 (c) Harmonic Spectrum of Source Current

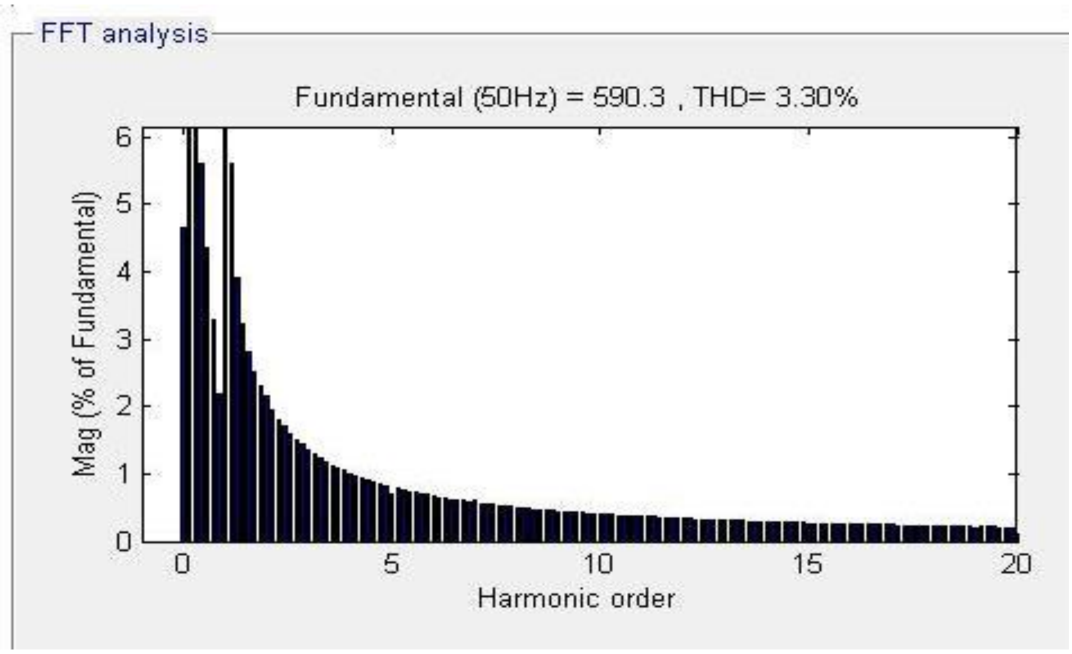


Fig. 7.2 (d) Harmonic Spectrum of Source Voltage

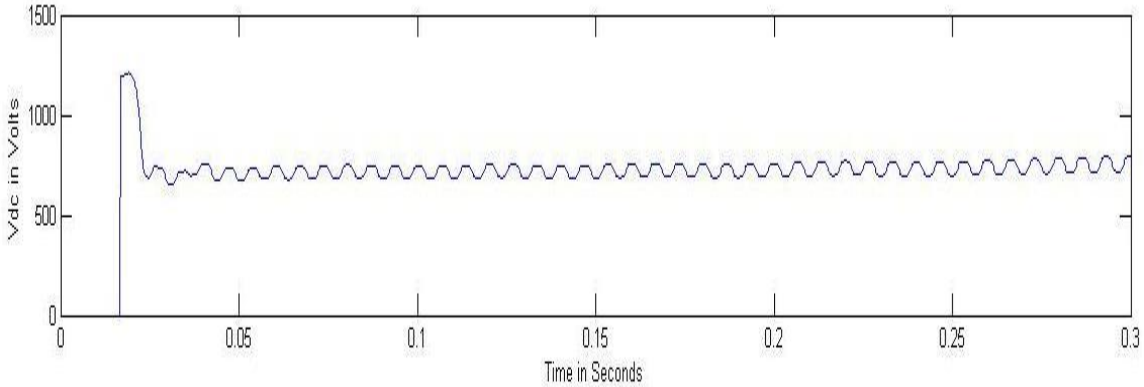


Fig. 7.2 (e) DC bus Voltage With PI Controller

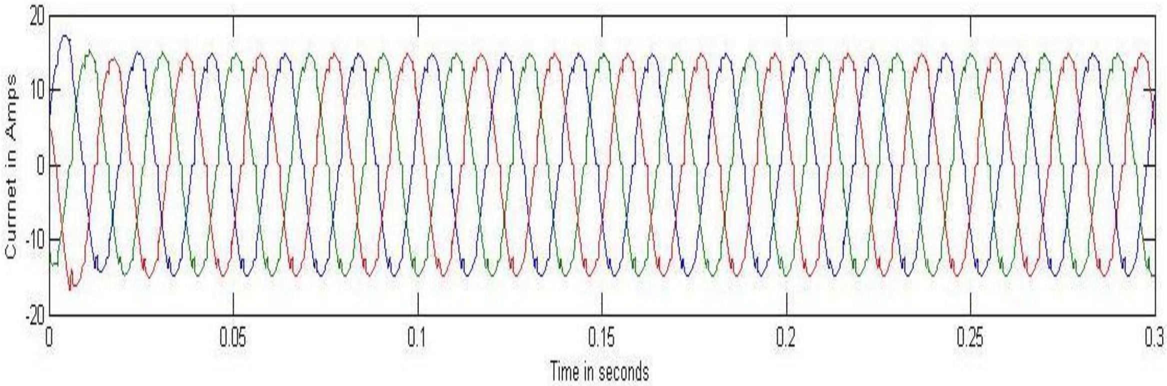


Fig. 7.2 (f) Filter Currents

From above plots (Fig 7.1(b) &7.2(c)) it can be concluded that the THD in the supply current has decreased from 26.44 to 4.28% .

7.4 Performance with Fuzzy Logic Voltage Controller and Fixed Hysteresis band current Controller:

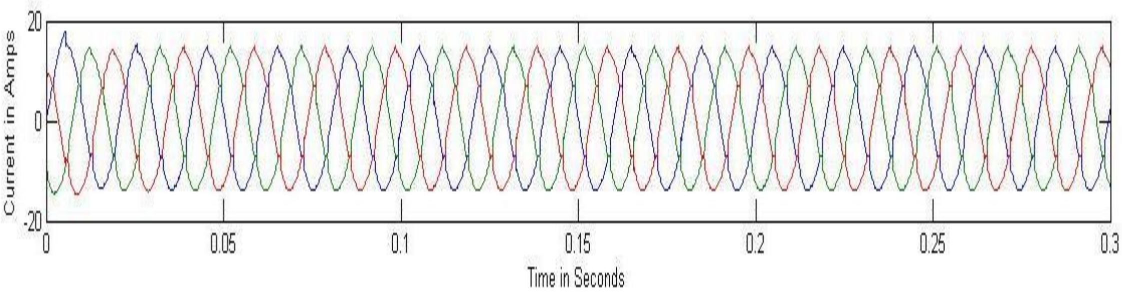


Fig 7.3(a) Source Current

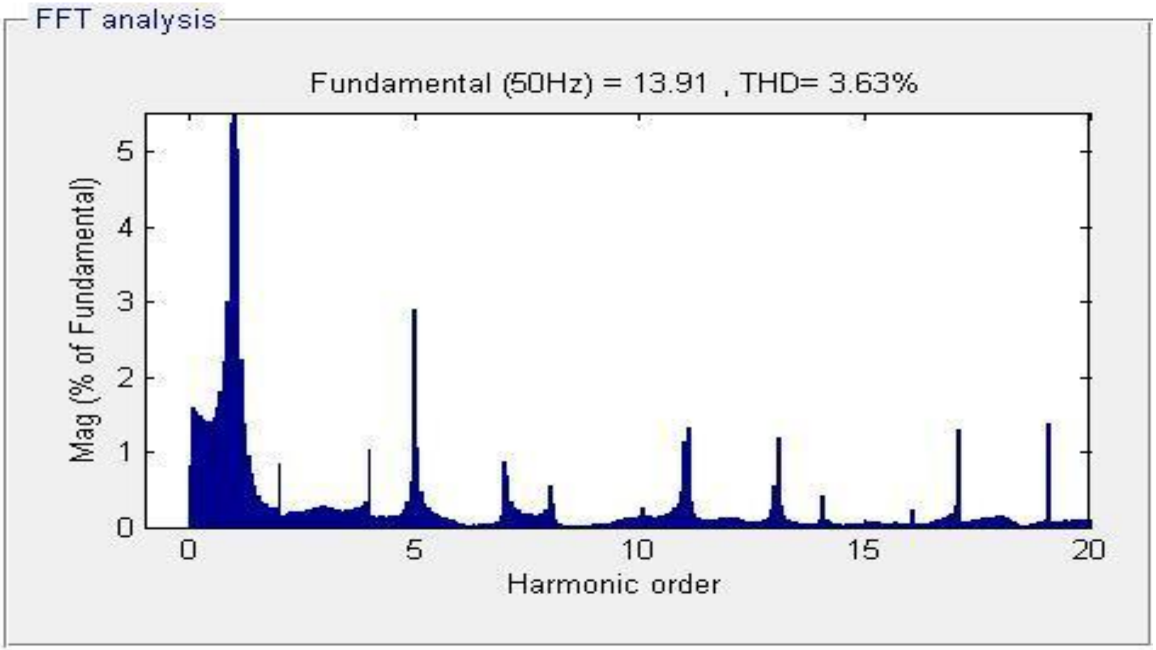


Fig 7.3 (b) Harmonic Spectrum of Source Current

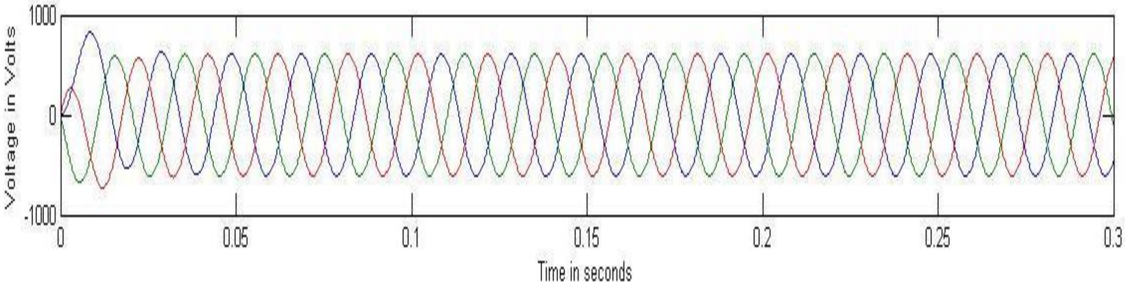


Fig 7.3(c) Source Voltage

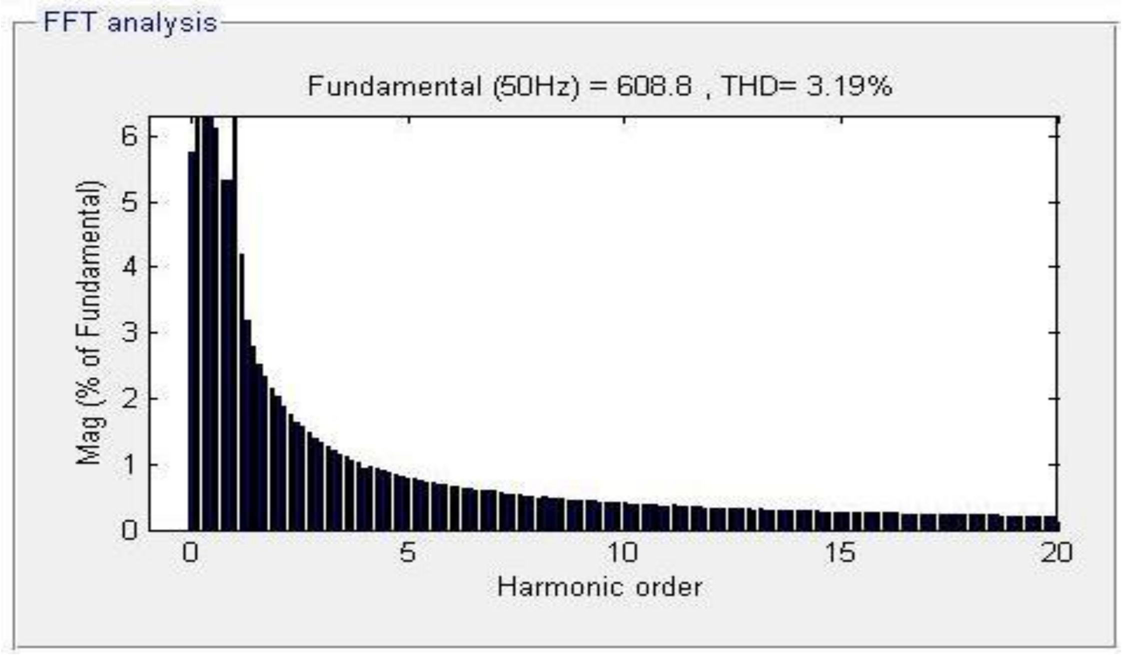


Fig. 7.3 (d) Harmonic Spectrum of Source Voltage

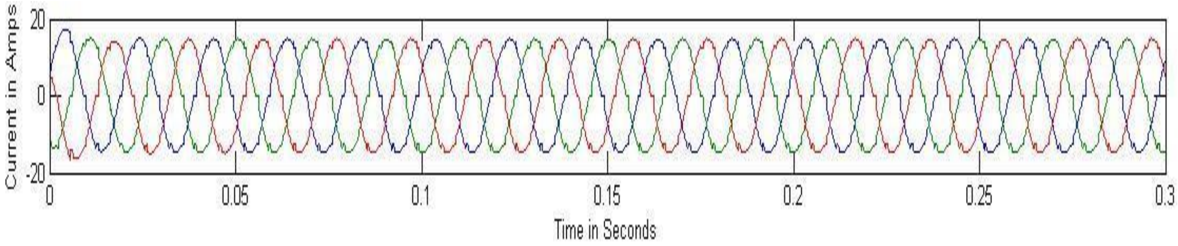


Fig. 7.3 (e) Filter Currents

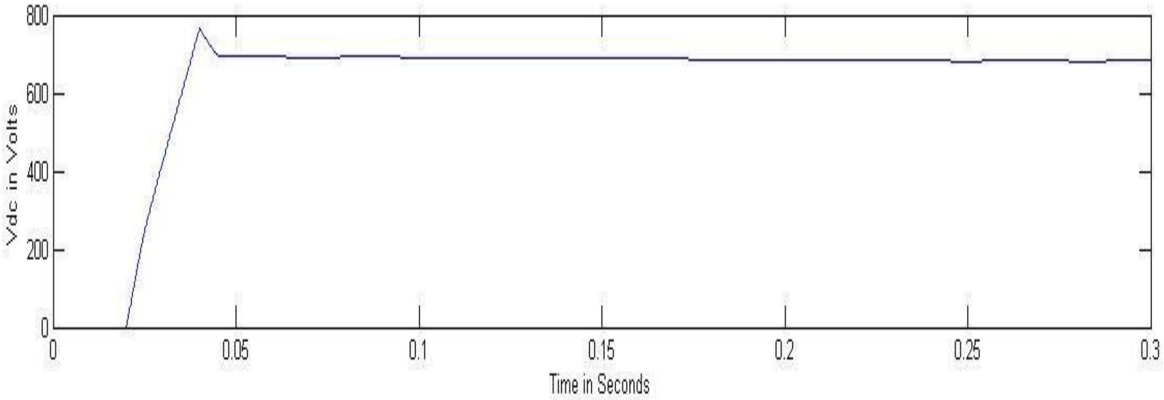


Fig. 7.3 (f) DC bus Voltage With Fuzzy logic Controller

The performance of PI and fuzzy controller in maintaining DC bus voltage is shown in Fig 7.2(e) & 7.3(f). It is observed that the DC bus voltage is exactly maintained at the reference value by the fuzzy logic controller, whereas some deviations are present with the PI Controller.

In this method Harmonic content in the supply current has reduced and the THD has decreased from 26.44 to 3.63% as shown in Fig 7.1(b) and Fig 7.3(b)

7.5 Performance with Fuzzy Logic Voltage Controller and Adaptive Hysteresis band current Controller:

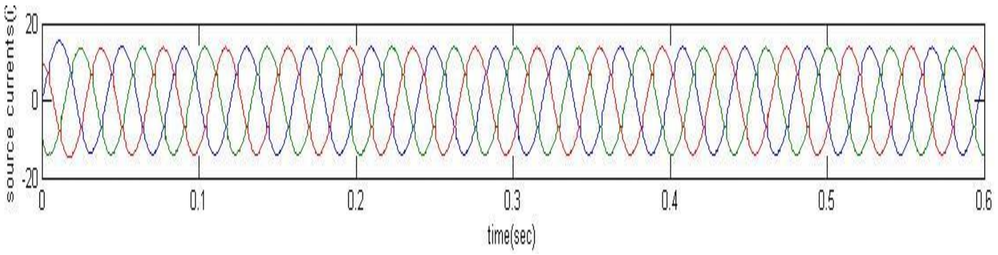


Fig. 7.4(a) Source Current

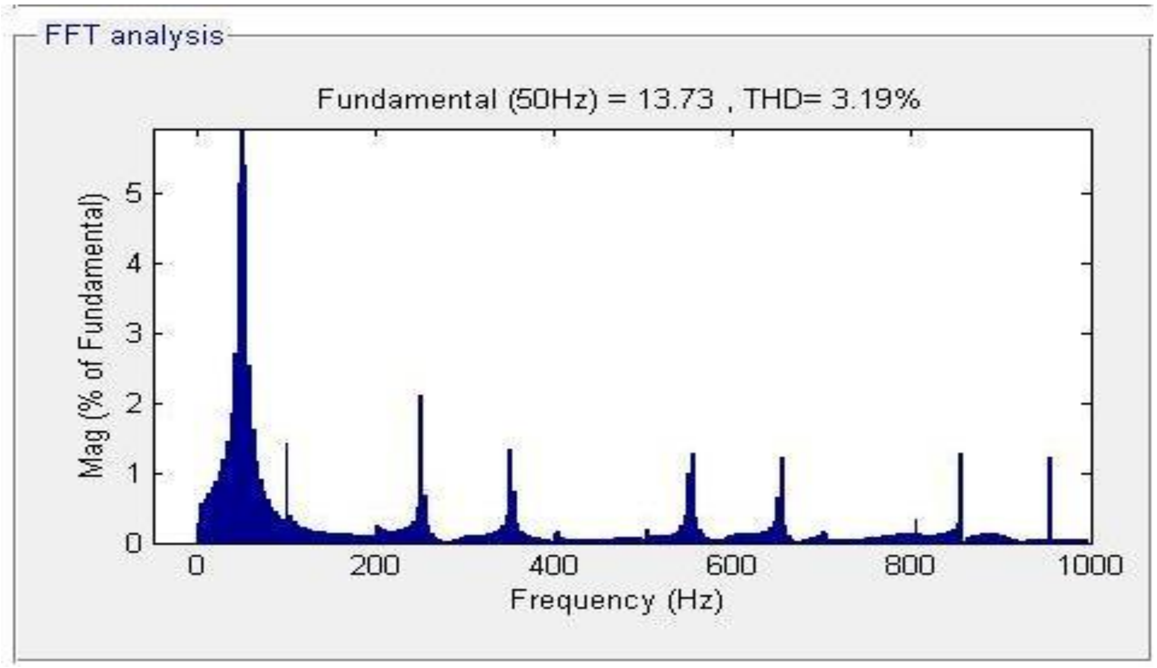


Fig. 7.4(b) Harmonic Spectrum of Source Current

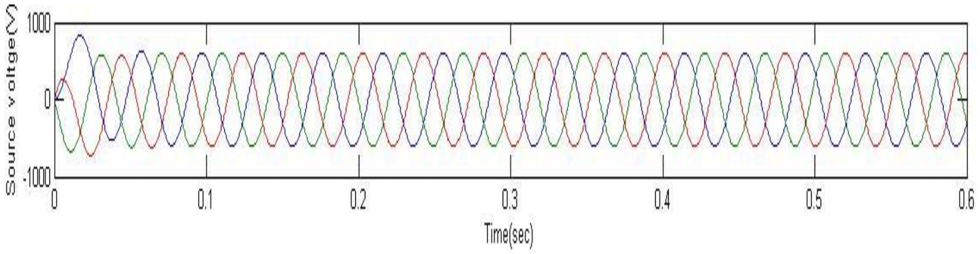


Fig. 7.4 (c) Source Voltage

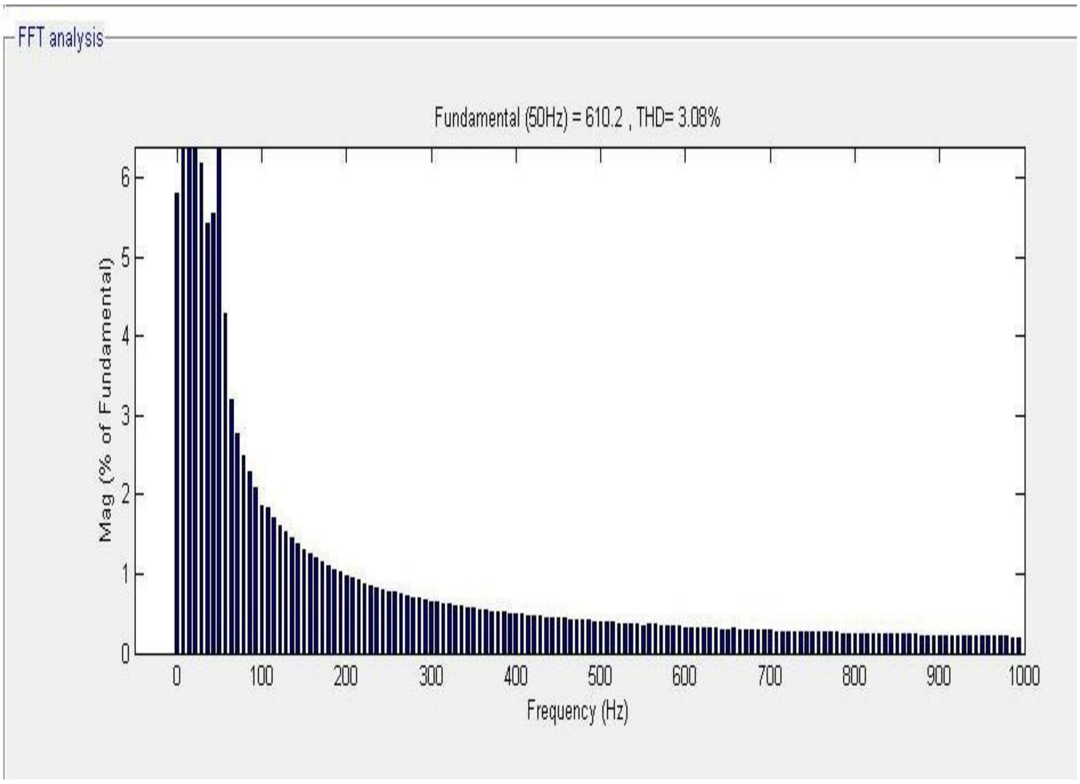


Fig. 7.4(d) Harmonic Spectrum of Source Voltage

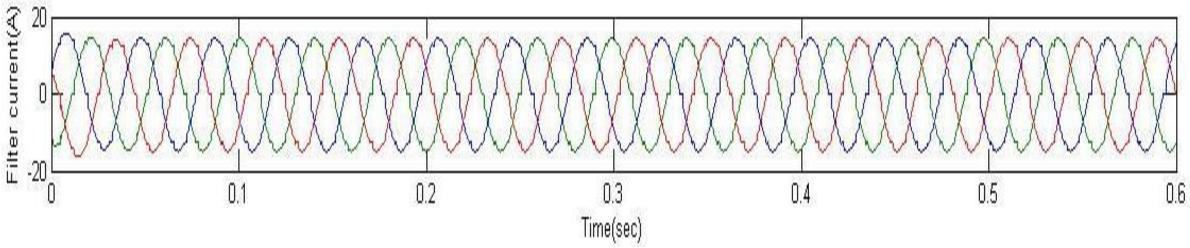


Fig. 7.4(e) Filter Currents

7.6 Performance with Fuzzy Logic Voltage Controller and Fuzzy-Adaptive Hysteresis band current Controller:

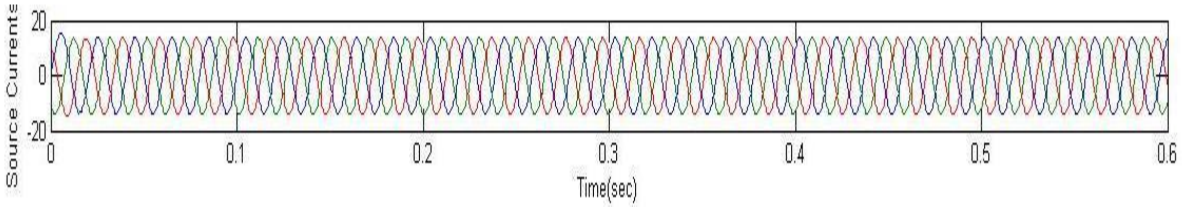


Fig. 7.5(a) Source Currents

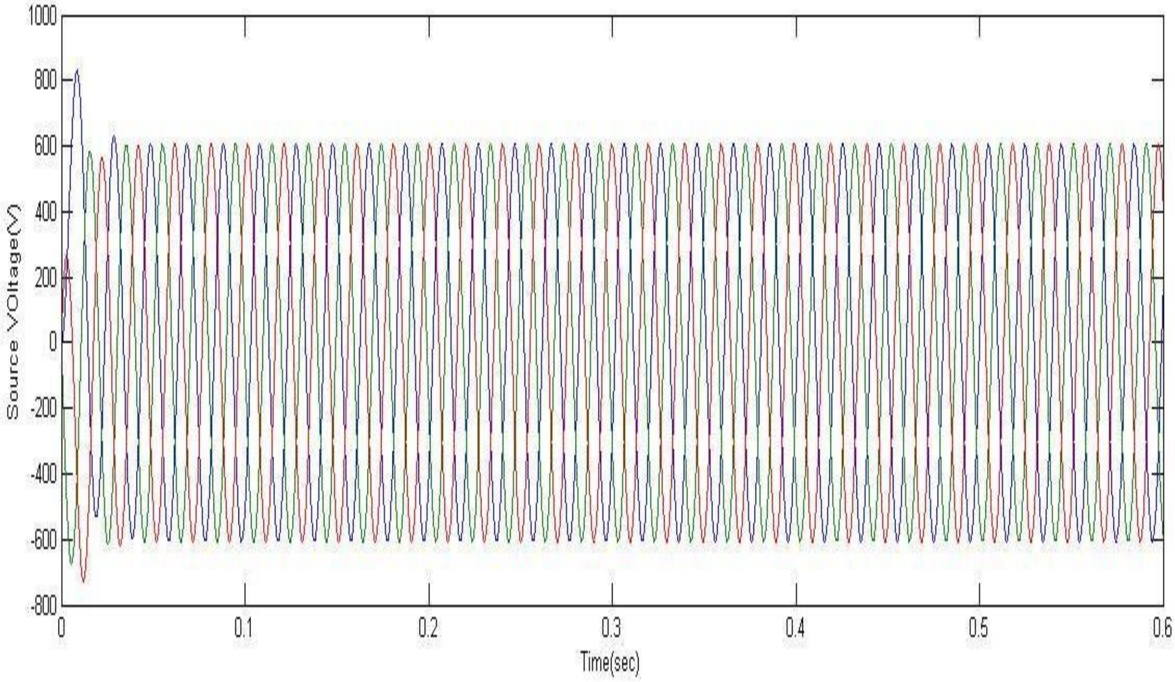


Fig. 7.5(b) Source Voltages

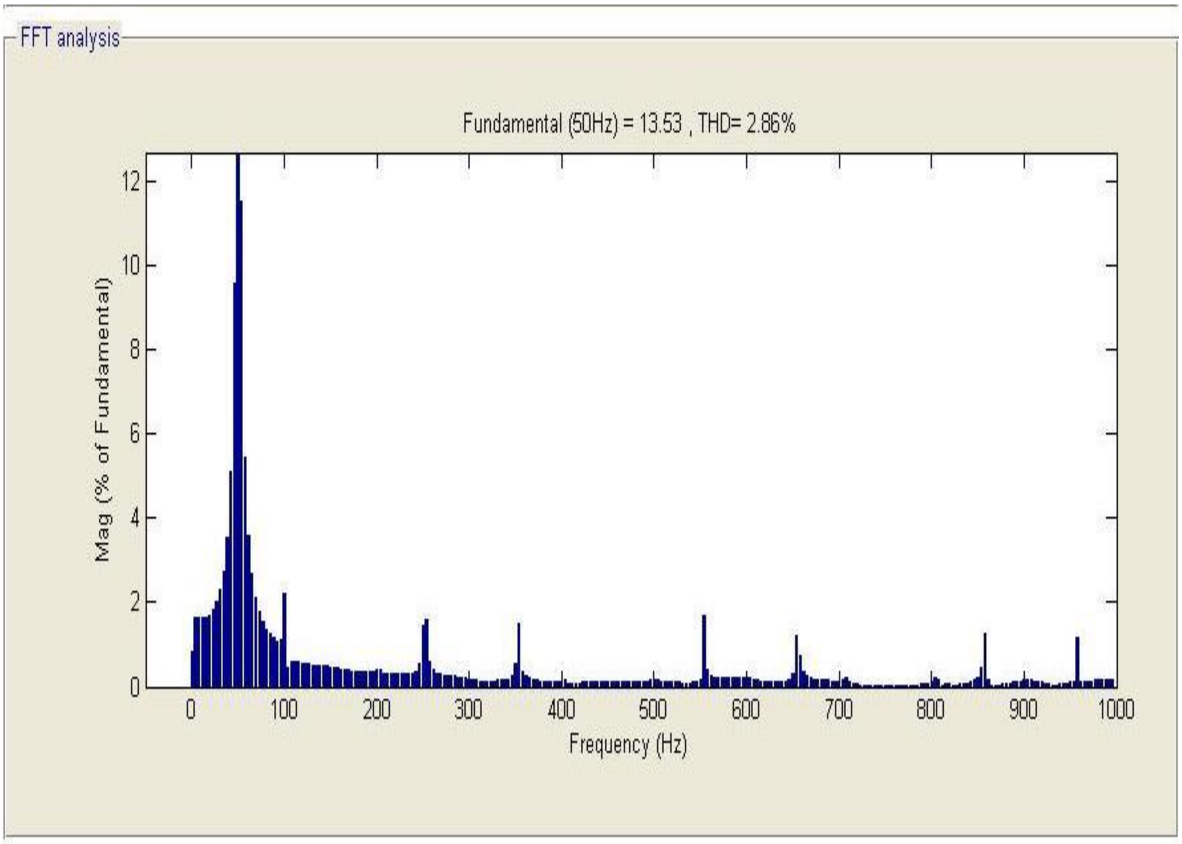


Fig 7.5(c) Harmonic Spectrum of Source Current

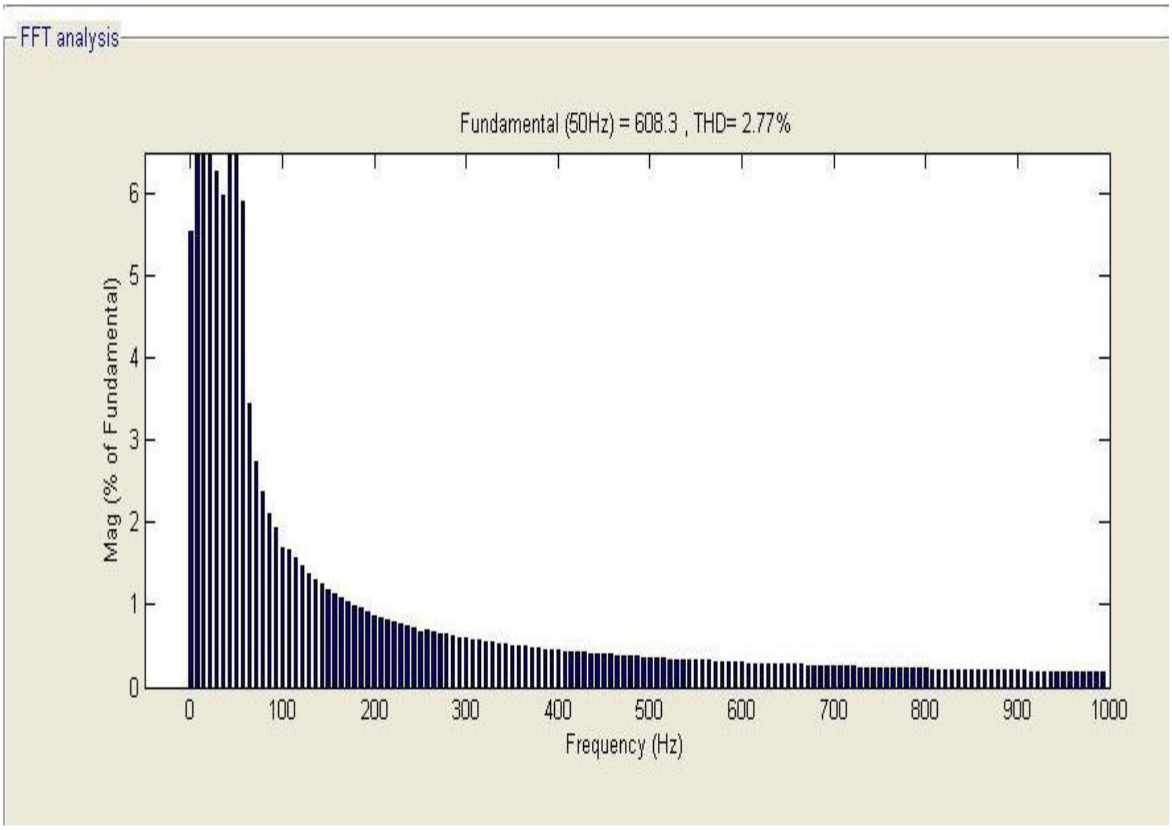


Fig. 7.5(d) Harmonic Spectrum of Source Voltage

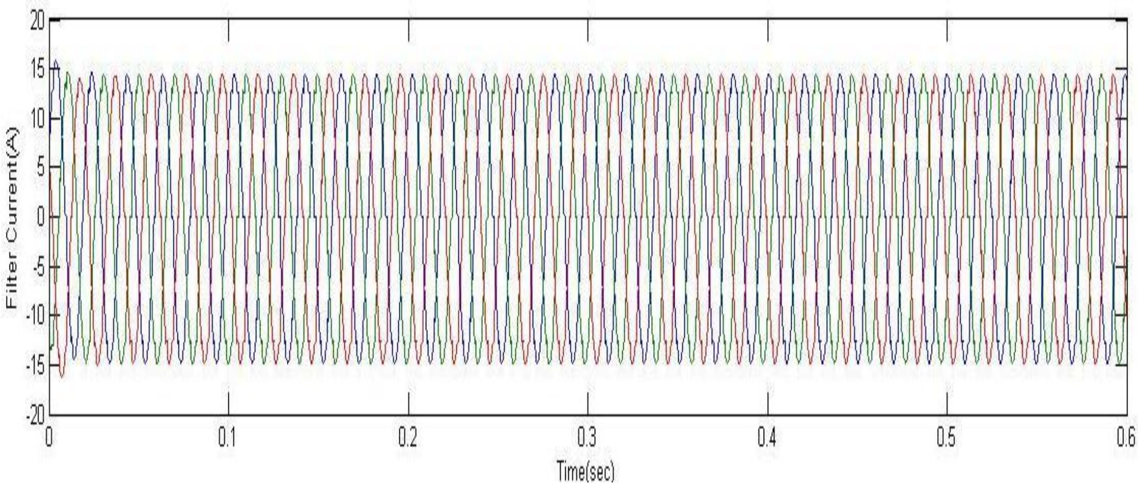


Fig. 7.5(e) Filter Currents

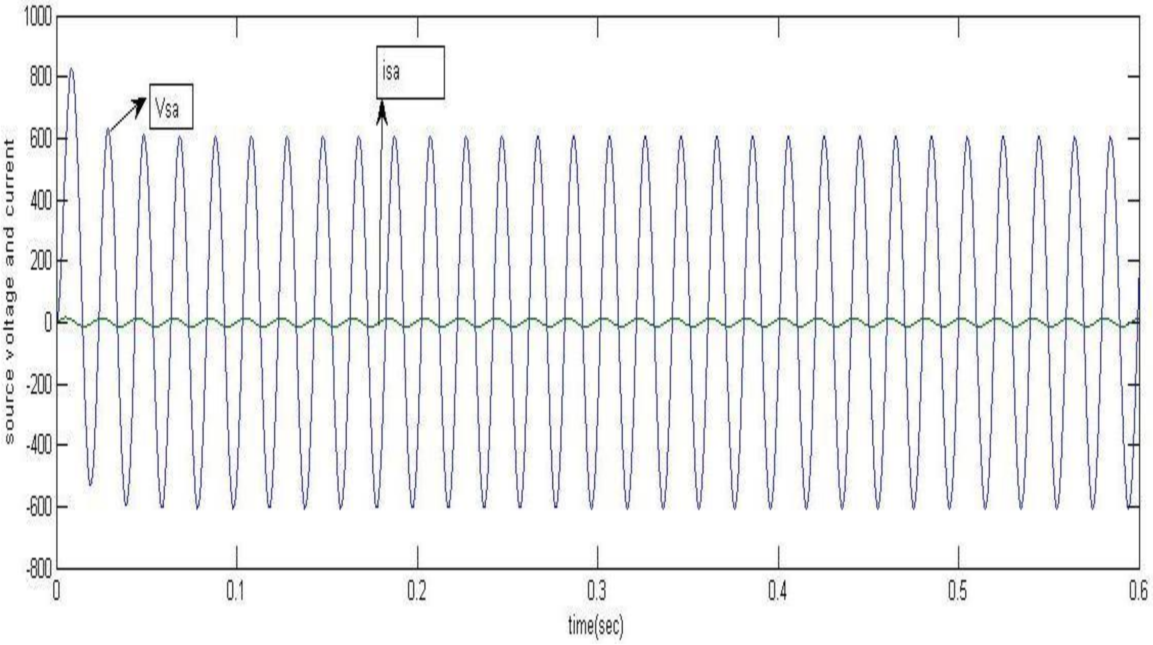


Fig. 7.5(f) Source Voltage and current

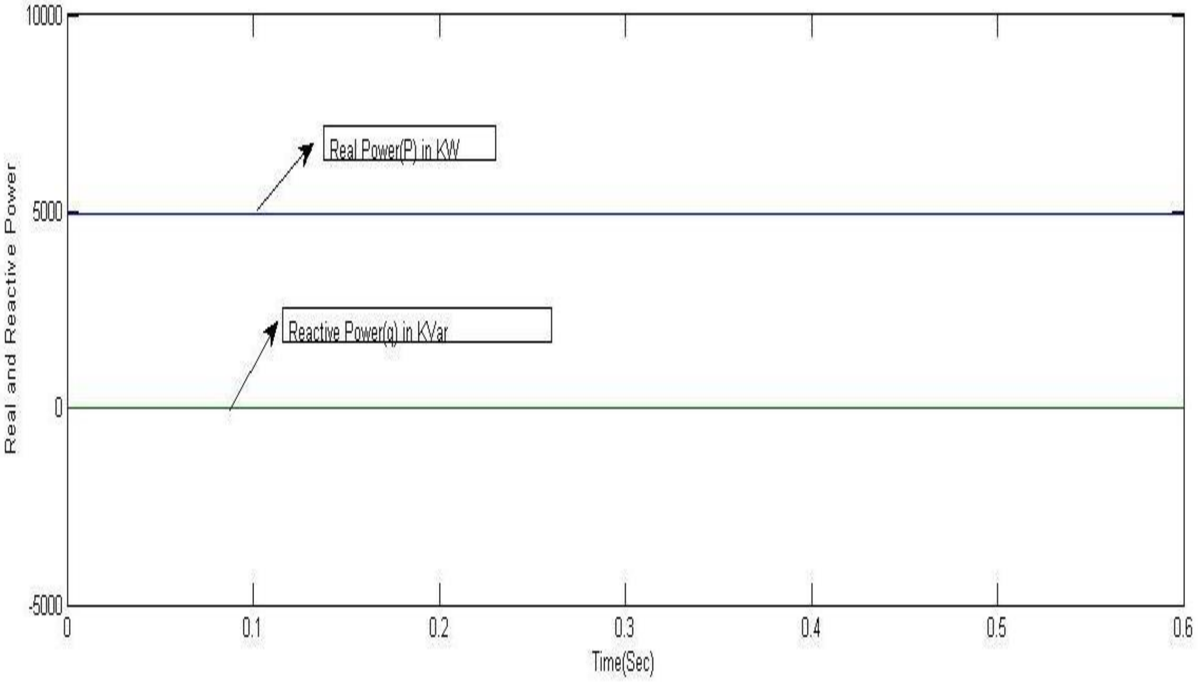


Fig. 7.5(g) Real and Reactive power supplied by the source to the load

7.7 Performance with Neural Network Voltage Controller and Fixed Hysteresis band current Controller:

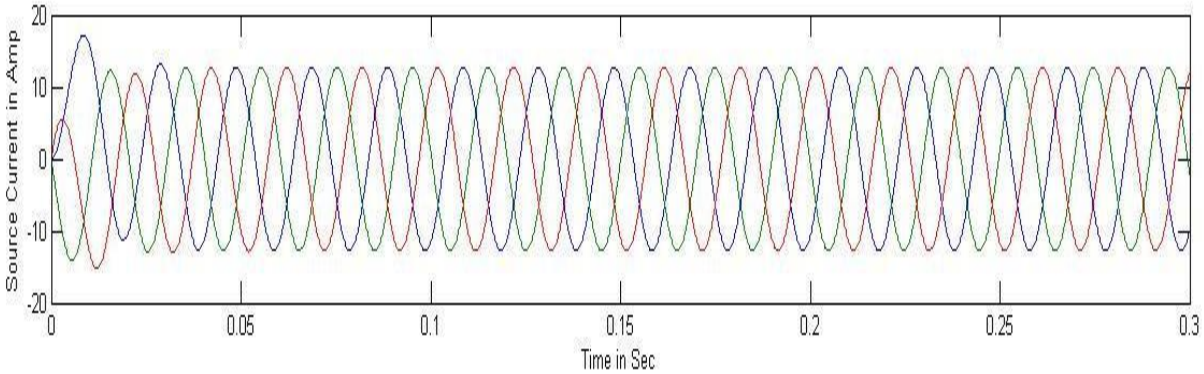


Fig. 7.6(a) Source Currents

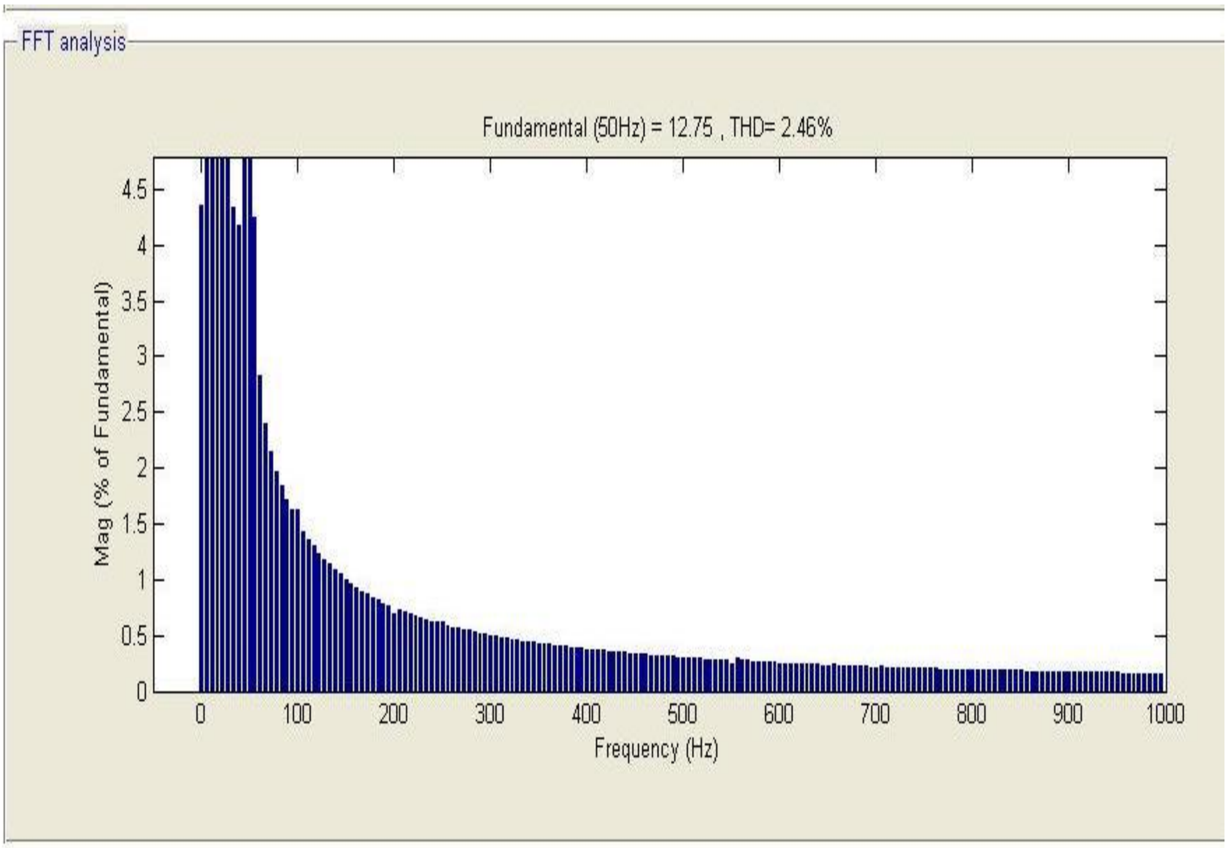


Fig. 7.6(b) Harmonic Spectrum of Source Currents

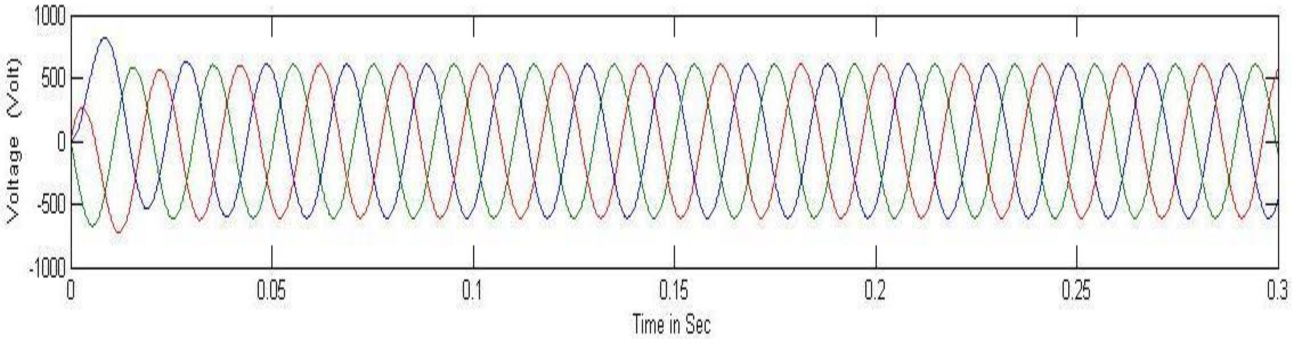


Fig. 7.6(c) Source Voltage

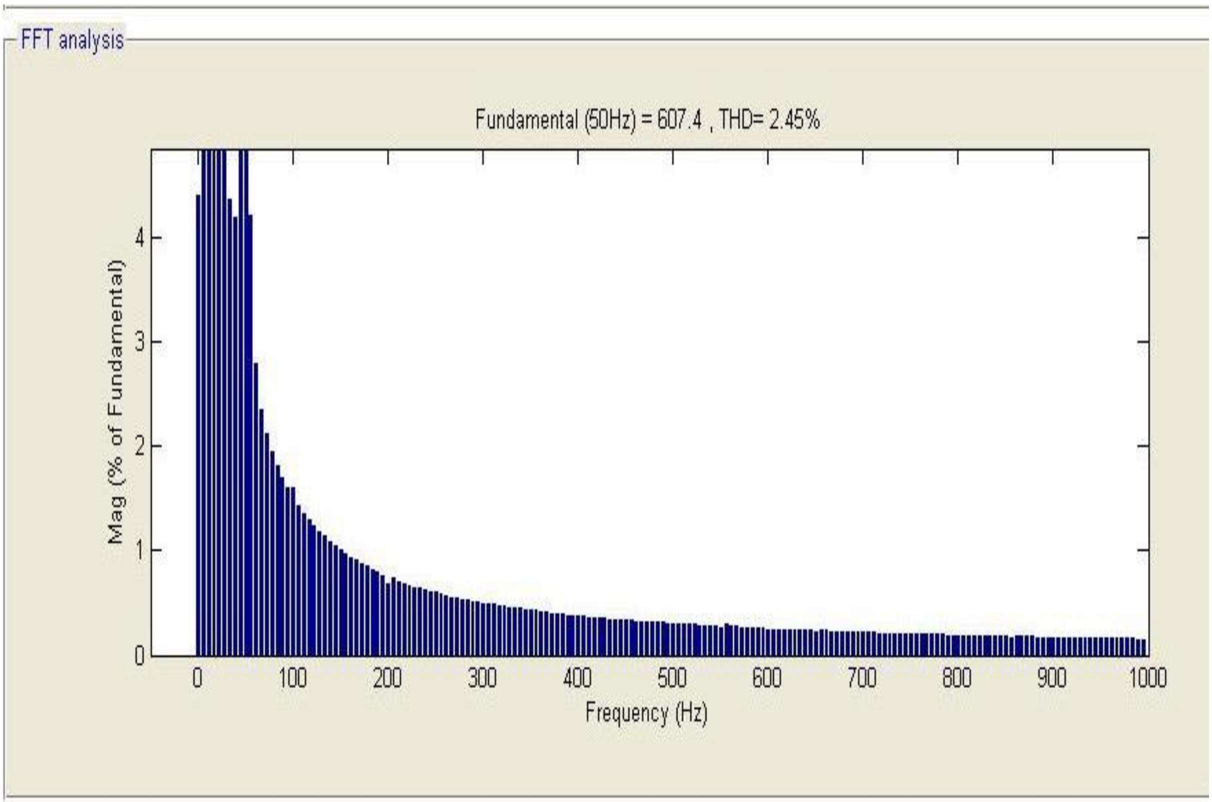


Fig. 7.6(d) Harmonic Spectrum of Source Voltage

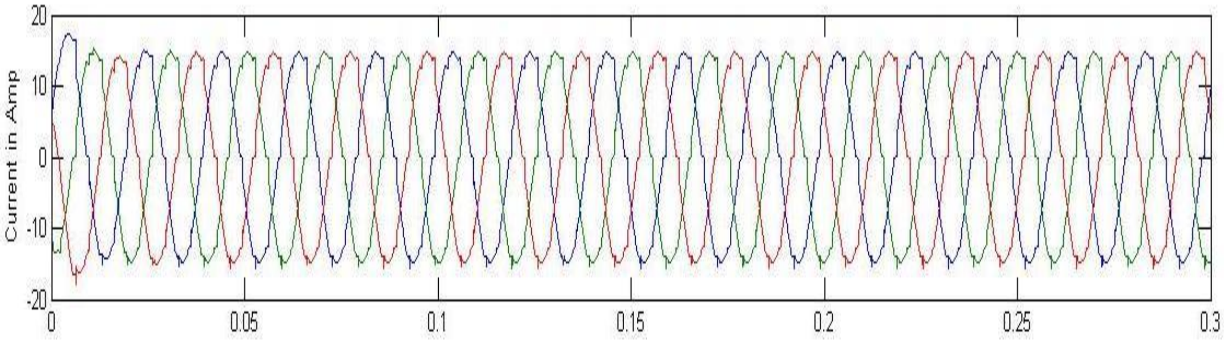


Fig. 7.6(e) Filter Currents

CHAPTER 8

CONCLUSION AND FUTURE SCOPE

8.1 CONCLUSION:

From the above simulation Results the performance of both PI and Fuzzy, Neural Network controllers for DC voltage controller With Fixed Hysteresis and Adaptive hysteresis band current controller techniques can be summarized as in Table 8.1.

Table 8.1: Comparision of Harmonic Distortion in Source Current and Source Voltages with Different voltage and current control techniques.

DC Voltage Control Technique	**Current Control Technique**	**Source Current THD(%)**	**Source Voltage THD(%)**
With Out Filter		26.44	25.76
PI	Fixed Hysteresis	4.28	3.30
Fuzzy	Fixed Hysteresis	3.63	3.19
Fuzzy	Adaptive Hysteresis	3.19	3.08
Fuzzy	Fuzzy-adaptive Hysteresis	2.86	2.77
Neural Network	Fixed Hysteresis	2.46	2.45

An adaptive hysteresis based fuzzy logic controlled shunt active power filter has been studied to improve the power quality by compensating harmonics and reactive power requirement of the nonlinear load. Supply current is maintained sinusoidal in phase with supply voltage resulting in unity power Factor. The simulation results show that the Neural Network Controller regulates the dc bus better than the fuzzy logic controller and PI Controllers.

The performance of fuzzy-adaptive hysteresis based current controller for reactive volt ampere compensator and harmonic suppressor has been studied and compared with Fixed hysteresis band current controller technique. Superior performance of the system has been observed, which is able to reduce the harmonics below 5% in all cases studied, the harmonic limit imposed by the IEEE-519 standard.

8.2 FUTURE SCOPE:

A hybrid neuro-fuzzy system to build a more powerful intelligent system with improved design and performance features can be applied to SAPF such as the Adaptive network-based fuzzy inference system(ANFIS) will give better performance results. These control algorithms will also applied to Series Active Power filter, Unified Power Quality Conditioner (UPQC's) and hybrid active filters for different applications of Power Quality Improvement.

Recently, genetic algorithm has been proposed for the design of membership functions and rule sets, which can be used for present fuzzy membership designs.

Real time implementation of above suggested APF can be implemented by using dSPACE software. dSPACE is an interface between the pc and real time systems. Software program is developed on pc and it can be transferred to the real time system via dSPACE. Complex controller algorithms can be developed and executed in pc and can be used to control the real-world system by interfacing it with dSPACE.

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