POWER QUALITY IMPROVEMENT USING SHUNT HYBRID POWER FILTER

A Thesis submitted in partial fulfillment of the requirements for the degree of Master of Technology

In
Electrical Engineering
(Control & Automation)

By

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DEPARTMENT OF ELECTRICAL ENGINEERING

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CERTIFICATE

This is to certify that the thesis entitled, **"POWER QUALITY IMPROVEMENT USING SHUNT HYBRID POWER FILTER"** submitted by **Mili Barai**, **(Roll No-210EE3231)** in partial fulfillment of the award of Master of Technology Degree in Electrical Engineering with specialization in **Control and Automation** during the period **2010-12** at the National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

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

Date: 14-05-2012
Place: Rourkela

Prof. K.B. Mohanty
Dept. of Electrical Engineering
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Rourkela - 769008

Dedicated

to

My beloved Parents

and

Brother

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MILI BARAI

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ABSTRACT

This project report presents design, simulation and development of passive shunt filter and shunt hybrid power filter (SHPF) for mitigation of the power quality problem at ac mains in ac-dc power supply feeding to a nonlinear load. The power filter is consisting of a shunt passive filter connected in series with an active power filter. At first passive filter has been designed to compensate harmonics. The drawback associated with the passive filter like fixed compensation characteristics and resonance problem is tried to solve by SHPF. Simulations for a typical distribution system with a shunt hybrid power filter have been carried out to validate the presented analysis. Harmonic contents of the source current has been calculated and compared for the different cases to demonstrate the influence of harmonic extraction circuit on the harmonic compensation characteristic of the shunt hybrid power filter.

Key Words: Shunt passive filter, shunt hybrid power filter, harmonic compensation, modeling.

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1.1 INTRODUCTION

Now a day's power electronic based equipment are used in industrial and domestic purpose. These equipments have significant impacts on the quality of supplied voltage and have increased the harmonic current pollution of distribution systems. They have many negative effects on power system equipment and customer, such as additional losses in overhead and underground cables, transformers and rotating electric machines, problem in the operation of the protection systems, over voltage and shunt capacitor, error of measuring instruments, and malfunction of low efficiency of customer sensitive loads.

Passive filter have been used traditionally for mitigating the distortion due to harmonic current in industrial power systems. But they have many drawbacks such as resonance problem, dependency of their performance on the system impedance, absorption of harmonic current of nonlinear load, which could lead to further harmonic propagation through the power system [2].

To overcome of such problem active power filters is introduced. It has no such drawbacks like passive filter. They inject harmonic voltage or current with appropriate magnitudes and phase angle into the system and cancel harmonics of nonlinear loads. But it has also some drawbacks like high initial cost and high power losses due to which it limits there wide application, especially with high power rating system. [3].

To minimize these limitations, hybrid power filter have been introduced and implemented in practical system applications [4] - [8]. Shunt hybrid filter is consists of an active filter which is connected in series with the passive filter and with a three phase PWM inverter. This filter effectively mitigates the problem of a passive and active filter. It provides cost effective harmonic compensation, particularly for high power nonlinear load [5]. Different control techniques are present for extracting harmonic components of the source current. Some of them are synchronous reference frame (SRF) transformation, instantaneous power (p-q) theory, etc. where high pass filters (HPFs) are used or extracting harmonic components of the source current from the fundamental components [6].

In This thesis, a shunt hybrid power filter (SHPF) is modeled in the stationary "a-b-c" reference frame and then, the model is transformed into the rotating "d-q" reference frame to reduce the control complexity. Two different decoupled current control techniques using proportional–integral (PI)-type controller and hysteresis controller, are implemented to force the current of the filter to track their reference value. On the other hand the dc-voltage of the filter is regulated using P-I controller. The harmonic current of the non-linear load is controls by feeding it to the passive filter, hence no harmonic currents are drawn from the ac mains. LC passive filter is connected with an active filter; the required rating of the active filter is much smaller than that of a stand-alone shunt active filter. Here switching ripple filter is not required because its LC circuit accomplishes the filtering of the switching ripple.

The model is first simulated with the P-I controller and then with the hysteresis controller. Simulation results of both the schemes are observed and it is confirmed the effectiveness of the SHPF in damping and mitigation of harmonics.

1.2 OBJECTIVE

- Design of passive filter for the ac - dc supply system feeding nonlinear load.
- Design of shunt hybrid power filter for ac- dc supply system feeding nonlinear load.
- Simulate both schemes in MATLAB/SIMULINK environment.
- Carry out the comparative study of both schemes on the basis of simulation response.

The diode rectifier interface to the electric utility exhibits nonlinear characteristics, which deteriorate the power quality at the ac mains. The present work aims to eliminating the problem of harmonic in the ac main.

In this research work, various alternatives such as passive filter, active filter, hybrid filter, six pulses PWM converter are implemented.

1.3 IMPORTANCE OF POWER QUALITY

- Power quality is defined by the parameters that express reactive power, harmonic pollution, and load unbalance.
- The best ideal electrical supply would be a sinusoidal voltage waveform with constant magnitude and frequency. But in reality due to the non-zero impedance of the supply system, the large variety of loads may be encountered and of other phenomena such as transients and outages, the reality is often different.
- If the power quality of the network is good, then any load connected to it will run satisfactorily and efficiently. Installation during cost and carbon footprint will be minimal.

- If the power quality of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will reduce. Installation running cost and carbon footprint will be high and operation may not be possible at all.

1.4 COST OF POOR POWER QUALITY

Poor Power Quality can be described as any event related to the electrical network that ultimately results in a financial loss. Possible consequences of Poor Power Quality include the followings:

- Unexpected power supply failures (breakers tripping, fuses blowing).
- Equipment failure or malfunctioning.
- Equipment overheating (transformers, motors,) leading to their lifetime reduction.
- Damage to sensitive equipment (PCs, production line control systems,).
- Electronic communication interferences.
- Increase of system losses.
- Need to oversize installations to cope with additional electrical stress with consequential increase of installation and running costs and associated higher carbon footprint.
- Penalties imposed by utilities because the site pollutes the supply network too much.
- Connection refusal of new sites because the site would pollute the supply network too much.
- Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time (flicker).
- Health issues with and reduced efficiency of personnel.

The following main contributors to low voltage and poor power quality can be defined:

- Reactive power, which unnecessarily loads up the supply system.
- Harmonic pollution, which causes extra stress on the networks and makes installations run less efficiently.
- Load imbalance, especially in office building applications, as the unbalanced loads may result in excessive voltage imbalance causing stress on other loads connected to the same network, and leading to an increase of neutral current and neutral to earth voltage build-up.
- Fast voltage variations leading to flicker.

If due to poor power quality the production is stopped, major costs are incurred.

1.5 POWER QUALITY PARAMETERS (TERMINOLOGY)

1.5.1 REACTIVE POWER AND POWER FACTOR (COS ϕ):

In AC supply, the current is usually phase-shifted from the supply voltage. This leads to different power definition.

- The active power P[KW], it is responsible for the useful work, which is associated with the portion of the current which is in phase with the voltage.
- The reactive power Q[KVAR], it sustains the electromagnetic field used to make a motor operate, is an energy exchange (per unit of time) between reactive components of the

electrical system (capacitors and reactors) and source. It is associated with the portion of the current which is phase shifted by 90° with the voltage.

- The apparent power S[KVA], which is a geometrical combination of the active and the reactive powers, can be seen as the total power drawn from the network.

The ratio between the active power and the apparent power is referred to as the power factor ($\cos\phi$) and is a measure of efficient utilization of the electrical energy. Unity power factor ($\cos\phi$ that equals to 1) refers to the most efficient transfer of useful energy. A $\cos\phi$, which is equals to 0 refers to the most inefficient way of transferring energy.

1.5.2 HARMONIC DISTORTION:

The harmonic pollution is generally characterized by the total Harmonic Distortion or THD which is by definition equal to the ratio of the RMS harmonic content to the fundamental:

THDV= $\frac{\sqrt{V^2{}_{RMS} - V_1{}^2}}{V_1} = \frac{\sqrt{\sum_{k=2} V_K^2}}{V_1}$, where V_K is the kth harmonic component of the signal V.

This quantity, expressed in %, is very useful when the fundamental value component is implicitly given or known. Consequently, the THD is particularly relevant information for the voltage (as the rated voltage is known). In order to be able to gauge THD of the current, it is imperative that a fundamental frequency current reference be defined.

1.5.3 VOLTAGE UNBALANCE

Fortes cue has shown in the symmetrical components theory that any three phase system can be expressed as the sum of three symmetrical sets of balanced phasors i.e. the first set having the same phase sequence as the initial system (positive phase sequence), the second set having the inverse phase sequence (negative phase sequence) and the third one consisting of three phasors in phase (zero phase sequence or homopolar components). A normal three phase supply has the three phases of same magnitude but with a phase shifted by 120°. Any deviation (magnitude or phase) of one of the three signals will result in a negative phase sequence component and/or a zero phase sequence component. The definition of voltage unbalance is usually expressed as the ratio between the negative phase sequence component and the positive phase sequence component. This parameter is expressed in %. (Strictly speaking, the homopolar part should also be considered in the definition. However, as it is the negative phase sequence that is the most relevant for causing damage to direct online motors by creating a reverse torque, historically the unbalance definition is often limited to the one expressed in this paragraph).

1.6 COMPARISION BETWEE ACTIVE AND PASSIVE FILTER

ACTIVE FILTER:

- They use the active devices and resistor and capacitor. No inductor is used.
- As no inductor is used circuit becomes compact and less in weight even at low frequencies.
- It requires dual power supply.
- Input impedance is high.
- As the output impedance is low, it can drive the low impedance load.

- Load is isolated from the frequency determined by the network. So, variation in load does not affect the characteristic of the filter.
- It is possible to increase the gain.
- Parameters like gain, pass band, cut off frequency can be adjusted.
- High frequency response is limited by gain × band width product and slew rate.
- Variation in power supply voltage affects the output voltage. Feedback through common supply rail may cause oscillations.

PASSIVE FILTER:

These filters make use of the passive components like inductor, capacitor, resistor etc.

- Circuit becomes bulky and costly especially for low frequency because size of the inductor increases at lower frequency.
- It does not need power supply.
- Input impedance is less which loads the source.
- Output impedance is more. So, it cannot drive the low impedance load.
- Load is not isolated from the frequency determining network, So, variation in load may affects the characteristic of filter.
- It is not possible to increase the gain.
- It is not possible to adjust the parameters.
- No restriction at high frequency.
- No power supply is used. So output is not affected.
- No such problem arises.

1.7 COMPARISION BETWEEN SERIES AND SHUNT FILTER

SERIES FILTER:

- Series filter is connected in series with the circuit.
- It offers a high impedance path to harmonic currents at its tuned frequency.
- Series filter must carry full load currents.
- It is high in cost as compare to shunt filter.

SHUNT FILTER:

- Shunt filter is connected in parallel with the circuit.
- It offers a low impedance path to harmonic currents at its tuned frequency.
- Shunt filters carry only a fraction of the load current.
- It is low in cost as compare to series filter.

1.8 POWER QUALITY IMPROVEMENT USING LC PASSIVE FILTER

During last decade, passive LC filters have been used to eliminate harmonic currents and to improve the power factor of ac mains. However, these passive filters have many drawbacks such as tuning problems and series and parallel resonances [2]. To avoid this resonance between an existing passive filter and the supply impedance, typical shunt or series active filter topologies have been proposed in the literature [3].

1.9 POWER QUALITY IMPROVEMENT USING ACTIVE FILTER

Active filter suffer from high kilovolt-ampere rating. The boost-converter forming the shunt active filter requires high dc-link voltage in order to effectively compensate higher order harmonics. On the other hand, a series active filter needs a transformer that is capable to with stand full load current in order compensate for voltage distortion[4], [6].

1.10 POWER QUALITY IMPROVEMENT USING HYBRID FILTER

Hybrid filters provide cost-effective harmonic compensation particularly for high-power nonlinear load [7]. A parallel hybrid power filter system consists of a small rating active filter in series with a passive filter. The active filter is controlled to act as a harmonic compensator for the load by confining all the harmonic currents into the passive filter. This eliminates the possibility of series and parallel resonance [8], [9].

1.11 CONTROL STRATEGIS

A number of control concepts and strategies of active power filters have been reported in the literature [10]-[12]. The most popular are time domain methods such as the notch filter, the instantaneous reactive power theory, and the synchronous reference frame theory. In [11], a nonlinear control technique is proposed to enhance the dynamic performance of a shunt active power filter which is modeled in the synchronous orthogonal d-q frame. In [12], the authors reported an adaptive nonlinear control law to a three-phase three-level neutral-point-clamped boost rectifier operating under severe conditions. The control techniques consists in applying an adaptive nonlinear control to the exact nonlinear model of the rectifier obtained in the (d, q, 0) reference frame. In [12], linear and nonlinear controllers are employed for a three-level rectifier for harmonic and dc-voltage regulation.

1.12 CONCLUSION

This chapter focuses regarding the objective of the project and basic ideas of filter. We can know the importance of power quality, and its parameter. The types of filters and difference between them are elaborated in this chapter. It indicated the various research works which has been done in power quality improvement by using different types of filters in different areas.

Chapter 2

POWER QUALITY IMPROVEMENT USING PASSIVE FILTER

2.1 INTRODUCTION

The passive filters are used to mitigate power quality problems in six-pulse ac-dc converter. Apart from mitigating the current harmonics, the passive filters also provide reactive power compensation, thereby, further improving the system performance. For current source type of loads, generally, passive shunt filters are recommended [114]. These filters, apart from mitigating the current harmonics, also provide limited reactive power compensation and dc bus voltage regulation. However, the performance of these filters depends heavily on the source impedance present in the system because these filters act as sinks for the harmonic currents. For voltage source type harmonic producing loads, the use of series passive filter is recommended [114]. These filters block the flow of harmonic currents into ac mains, by providing high impedance path at certain harmonic frequencies for which the filter is tuned. Moreover, the harmonic compensation is practically independent of the source impedance. But, passive series filters suffer due to the reduction in dc link voltage drop across the filter components at both fundamental and harmonic frequencies.

This chapter presents a detailed investigation into the use of different configurations of passive shunt filters. The advantages and disadvantages are discussed. It is observed that these configurations fail to meet the IEEE standard 519 guidelines under varying load conditions. The configuration of passive hybrid filter is designed for power quality improvement. The main advantages of this configuration is that it can achieve the improved power quality even under varying load conditions, its rating is less and it can it can maintain the dc link voltage regulation within certain limits.

2.2 CLASSIFICATION OF PASSIVE FILTERS

Depending on the connection of different passive components, the passive filters are classified as below:

- Passive series filter
- Passive shunt filter

My scope of work is on shunt passive and hybrid filter.

2.2.1 SHUNT PASSIVE FILTER:

Fig.1. shows the schematic diagram of a passive shunt filter connected at input ac mains of six pulse ac-dc converters fed to a nonlinear load. This is the commonly used configuration of passive filter. It consists of a low pass shunt filters tuned at 5^{th} and 7^{th} harmonic frequencies and high pass filter tuned for 11^{th} harmonic frequencies. These passive filters scheme helps in sinking the more dominant 5^{th}, 7^{th} and other order harmonic and thus prevents them flowing into ac mains.

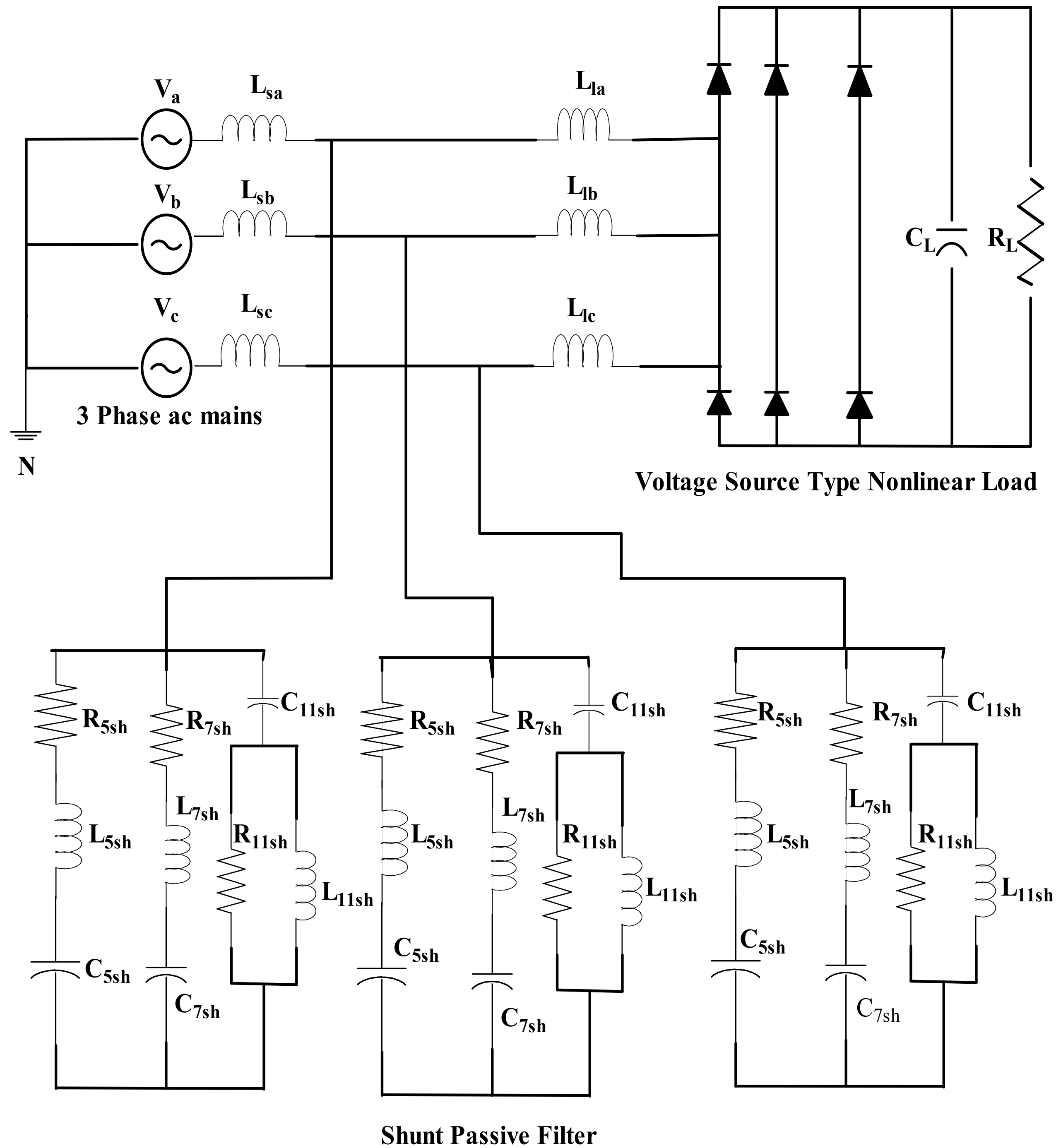


Fig.1 Schematic diagram of shunt passive filter with V-S Type nonlinear load

2.3 COMPENSATION PRINCIPLE OF SHUNT PASSIVE FILTER

A passive shunt filter consists of several LCR branches each tuned at particular frequency. Fig.2 shows the equivalent circuit diagram of a passive shunt filter. The compensation principle of LC passive shunt filter is as follows:

$$\frac{I_s}{V_1} = \frac{Z_{sh}}{Z_1 Z_s + Z_1 Z_{sh} + Z_s Z_{sh}} \tag{1}$$

Where Z_{sh} is the impedance of the parallel LC filter. From (1) it can be seen that the performance of parallel LC filter depends on the source impedance and is determined only by the ration of the source impedance and the filter impedance..

If $Z_1 = 0$, then $I_s = I_1$, which means that the passive filter is not effective. But if Zs = 0, then $\frac{I_s}{V_1} = \frac{1}{Z_1}$, which means that the filter does not provide harmonic compensation.

It is seen that the filter interaction with the source impedance results in a parallel resonance. For inductive source impedance (Z_s), this occurs at a frequency below the frequency at which the filter is tuned. It is as follows:

$$f_{sys} = \frac{1}{2\pi (L_s + L)C} \tag{2}$$

If the filter is tuned exactly at a concern frequency then an upward shift in the tuned frequency results in a sharp increase in impedance as seen by the harmonic. There are some common mechanisms which may cause filter detuning. They are as follows:

- Capacitor fuse-blowing, which lowers the total capacitance, thereby raising the frequency at the filter has been tuned.
- Temperature variation
- System parameter variation
- Manufacturing tolerances in both inductor as well as capacitor.

So the filter banks are tuned to around 6% below the desired frequency as per IEEE standard 1531 [23].

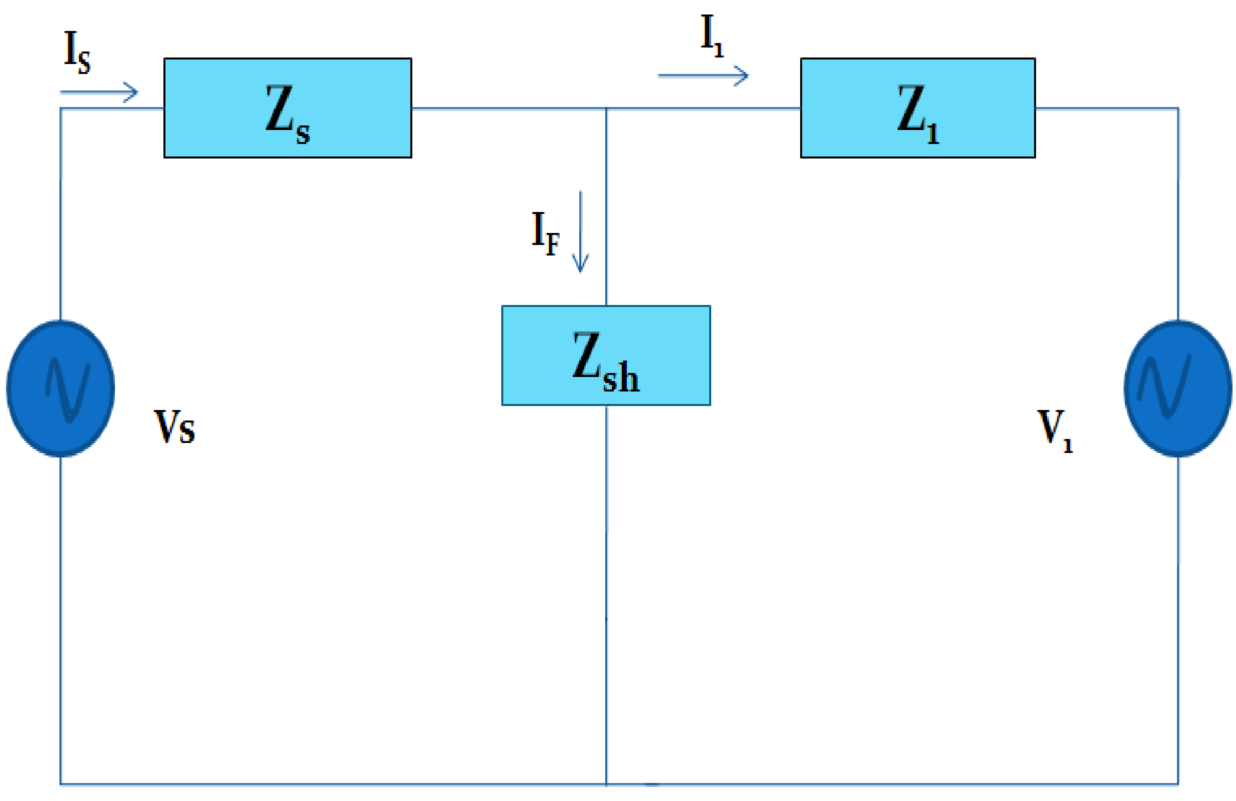


Fig.2 Equivalent circuit diagram of passive shunt filter based configuration

2.4 DESIGN OF SHUNT PASSIVE FILTER

The passive shunt filter consists of first order series tuned low pass filters tuned for 5th and 7th harmonics and a second order damped high pass filter tuned for 11th harmonics.

2.4.1 LOW PASS FILTER:

For the series tuned low pass filter the impedance is:

$$Z_{sh(h)} = \left[R + j(hX_L - \frac{X_C}{h} \right] \tag{3}$$

$$X_C = \frac{V_{ph}^{\ 2}}{Q_{sh} h} \tag{4}$$

$$X_L = \frac{X_C}{h_n^2} \tag{5}$$

Where Q_{sh} = reactive power provided by the passive filter in VAR per phase, X_L = reactance of inductor, X_C = reactance of capacitor, h = harmonic order of the passive filter, V_{ph}=Phase voltage

Initially the reactive power requirement is assumed to be 25% of the rating of the load [112]. It may be equally divided into different filter branches. The value of series tuned element can be calculated from (4) and (5). The quality factor of the low pass filter is:

$$QF = \frac{X_L}{R} \tag{6}$$

Here the quality factor is assumed to 30 to calculate the value of the resistive element. The resonant frequency is given by

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{7}$$

Where R = filter resistance

L = filter inductance

C = filter capacitance

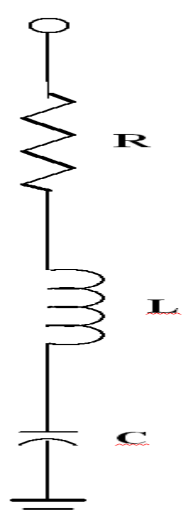


Fig.3. Low pass filter.

2.4.2 HIGH PASS FILTER:

For second order damped filter, the impedance at any harmonics h becomes:

$$Z_{sh} = \left[\frac{R(hX_L)^2}{R^2 + (hX_L)^2} + j\left(\frac{R^2 hX_L}{R^2 + (hX_L)^2} - \frac{X_C}{h}\right) \right] \tag{8}$$

$$X_C = (\frac{h_n^2}{h_n^2 - 1})\frac{V^2}{Q_{sh}} \quad (9)$$

Resonant frequency for hth harmonic is

$$f_0 = \frac{1}{2\pi hCR} \quad (10)$$

Quality factor can be expressed as

$$QF = \frac{L}{R^2C} \quad (11)$$

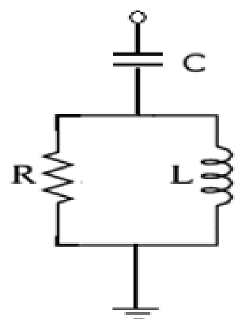


Fig.4. High pass filter.

The design of passive shunt filter is carried out as per the reactive power requirements. The filter is designed to compensate the reactive power of the system. Hence the passive filter helps in maintaining the regulation of dc link voltage within limits and power factor improvement as improving the THD of supply current. It also sinks the harmonic currents of the frequencies at which the passive filter has been tuned.

Depending on the harmonic spectrum of the supply current passive filter is designed for low pass filters which is tuned for 5^{th} and 7^{th} harmonic frequency and high pass filter which is tuned for 11^{th} harmonic frequency shown in Fig.1. In low pass filter Fig.3 R, L, and C are connected in series. The high pass filter Fig.4 consists of a capacitor which is connected in series with the parallel combination of the resistor and inductor to the converter.

In this research work passive LC filter is designed for the 5^{th} and 7^{th} order harmonic frequency, and the filter component values are:

Table 1

Passive Filter Components

5^{th}	C_5=11.24e-3	L_5=0.9e-3
7^{th}	C_7=15.7e-3	L_7=0.64e-3

2.5 CONCLUSION

This chapter described about the shunt passive filter. It elaborated the design and compensation principle of passive filter for low pass and high pass filter. In this project work the low pass filter is tuned for 5^{th} and 7^{th} order harmonic frequencies. The values of the filter component are given in table 1.

Chapter 3

POWER QUALITY IMPROVEMENT USING SHUNT HYBRID POWER FILTER

Introduction

Modeling of SHPF

Harmonic Current Control

Regulation of DC Voltage

Conclusion

3.1 INTRODUCTION

The schematic diagram of the shunt hybrid power filter (SHPF) is presented in Fig. 1. The scheme contains the three phase supply voltage, three phase diode rectifier and the filtering system consists of a small-rating active power filter connected in series with the LC passive filter. This configuration of hybrid filter ensures the compensation of the source current harmonics by enhancing the compensation characteristics of the passive filter besides eliminating the risk of resonance. It provides effective compensation of current harmonics and limited supply voltage distortion. The hybrid filter is controlled such that the harmonic currents of the nonlinear loads flow through the passive filter and that only the fundamental frequency component of the load current is to be supplied by the ac mains.

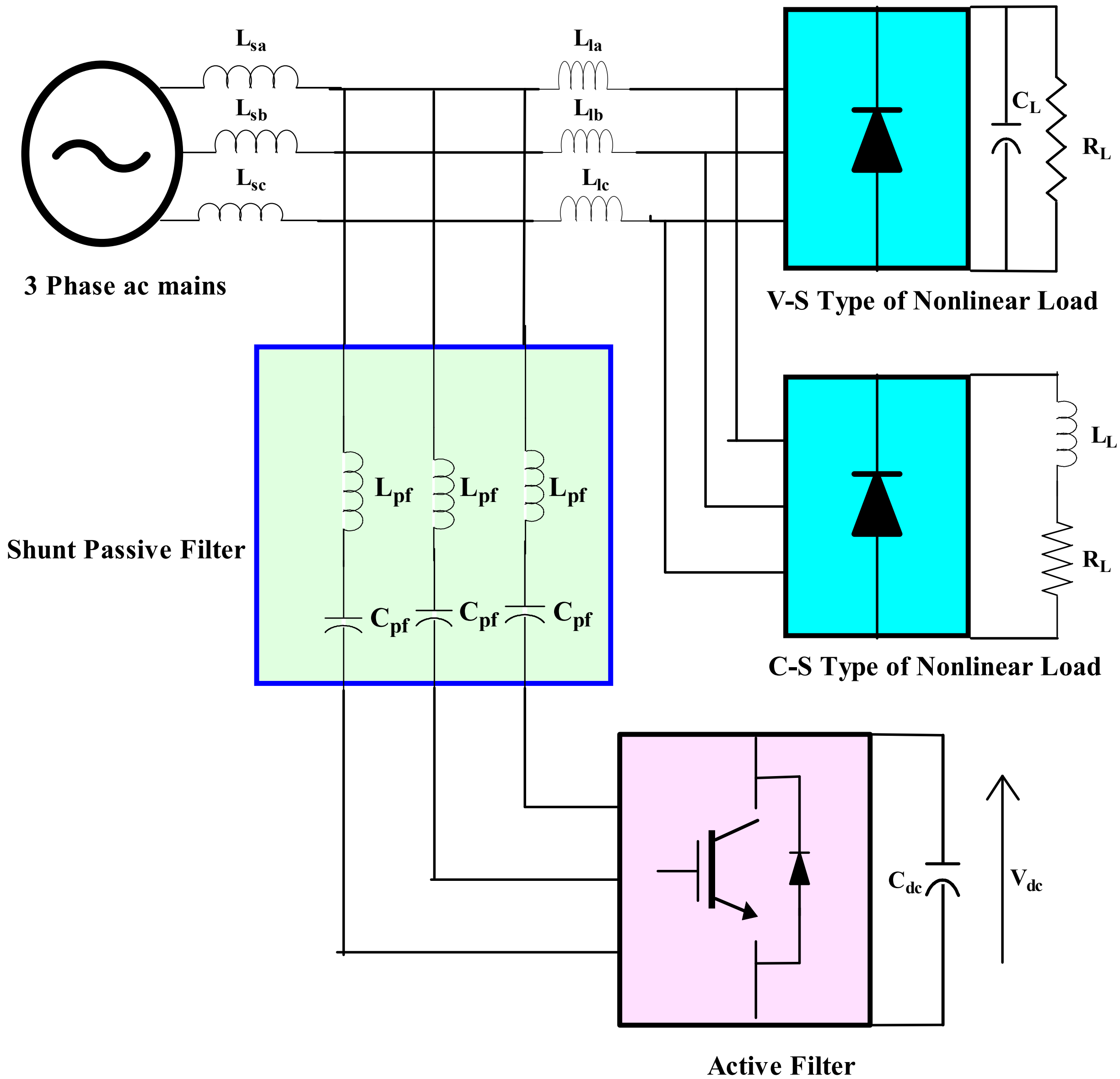


Fig.5 Schematic diagram of 3-phase SHPF Supplying power to Voltage Source Type and Current Source Type Nonlinear Load.

3.2 MODELLING OF THE SHPF

3.2.1 MODEL IN a-b-c REFERENCE FRAME:

Kirchhoff's law of voltage and currents applied to this system provide three differential equations in the stationary "a-b-c" frame (for k = 1, 2, 3)

$$v_{sk} = L_{PF}\frac{di_{ck}}{dt} + R_{PF}i_{ck} + \frac{1}{C_{PF}}\int i_{Ck}dt + v_{kM} + v_{MN} \tag{12}$$

Differentiating (12) we get

$$\frac{dv_{sk}}{dt} = L_{PF}\frac{d^2 i_{ck}}{dt^2} + R_{PF}\frac{di_{ck}}{dt} + \frac{1}{C_{PF}}i_{ck} + \frac{dv_{kM}}{dt} + \frac{dv_{MN}}{dt} \tag{13}$$

Assume that the zero sequence current is absent in a three phase system and the source voltages are balanced, so we obtain:

$$v_{MN} = -\frac{1}{3}\sum_{k=1}^{3} v_{kM} \tag{14}$$

We can define the switching function C_k of the converter k^{th} leg as being the binary state of the two switches S_k and S'_k. Hence, the switching C_k (for k = 1, 2, 3) is defined as

$C_k = 1$, if S_k is On and S'_k is Off ,

$C_k = 0$, if S_k is Off and S'_k is On. (15)

Thus, with $V_{kM} = C_k V_{dc}$, and from (15), the following relation is obtained:

$$\frac{d^2 i_{ck}}{dt^2} = -\frac{R_{PF}}{L_{PF}}\frac{di_{ck}}{dt} - \frac{1}{C_{PF}L_{PF}} i_{ck} - \frac{1}{L_{PF}}(c_k - \frac{1}{3}\sum_{m=1}^{3} c_m)\frac{dv_{dc}}{dt} + \frac{1}{L_{PF}}\frac{dv_{sk}}{dt} \tag{16}$$

Let the switching state function be defined as

$$q_{nk} = (c_k - \frac{1}{3}\sum_{m=1}^{3} c_m)_n \tag{17}$$

The value of q_{nk} depends on the switching state n and on the phase k. This shows the interaction between the three phases. Conversion from $[C_k]$ to $[q_{nk}]$ is as follows

$$q_{n1} = \frac{2}{3}c_1 - \frac{1}{3}c_2 - \frac{1}{3}c_3 \tag{18}$$

$$q_{n2} = -\frac{1}{3}c_1 + \frac{2}{3}c_2 - \frac{1}{3}c_3 \tag{19}$$

$$q_{n3} = -\frac{1}{3}c_1 - \frac{1}{3}c_2 + \frac{2}{3}c_3 \tag{20}$$

Hence we got the relation as

$$\begin{bmatrix} q_{n1} \\ q_{n2} \\ q_{n3} \end{bmatrix} = \frac{1}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} \tag{21}$$

The matrix in (21) is of rank 2 q_{nk} has no zero sequence components. By the analysis of the dc component of the system it gives

$$dv_{dc} = \frac{1}{c_{dc}} i_{dc} = \frac{1}{c_{dc}} \sum_{k=1}^{3} q_{nk} i_{ck} \tag{22}$$

With the absence of zero sequence components in i_k and q_{nk} one can gets

$$\frac{dv_{dc}}{dt} - \frac{1}{c_{dc}}(2q_{n1} + q_{n2})i_{c1} + \frac{1}{c_{dc}}(q_{n1} + 2q_{n2})i_{c2} \tag{23}$$

Hence the complete model of the active filter in "a-b-c" reference frame is obtained as follows

The application of (16) for phase 12 and 13 with (23)

$$L_{PF} \frac{d^2 i_{c1}}{dt^2} = -R_{PF} \frac{di_{c1}}{dt} - \frac{1}{C_{PF}} i_{c1} - q_{n1} \frac{dv_{dc}}{dt} + \frac{dv_{s1}}{dt}$$

$$L_{PF} \frac{d^2 i_{c2}}{dt^2} = -R_{PF} \frac{di_{c2}}{dt} - \frac{1}{C_{PF}} i_{c2} - q_{n2} \frac{dv_{dc}}{dt} + \frac{dv_{s2}}{dt}$$

$$C_{dc} \frac{dv_{dc}}{dt} = (2q_{n1} + q_{n2})i_{c1} + (q_{n1} + 2q_{n2})i_{c2} \tag{24}$$

The above model is time varying and nonlinear in nature.

3.2.2 MODEL TRANSFORMATION INTO "d-q" REFERENCE FRAME:

Since the steady state fundamental components are sinusoidal, the system is transformed into the synchronous orthogonal frame rotating at constant supply frequency. The conversion matrix is

$$C_{dq}^{123} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta - 4\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta - 4\pi/3) \end{bmatrix} \tag{25}$$

where θ = ωt, and the following equalities hold:

$$C_{123}^{dq} = (C_{dq}^{123})^{-1} = (C_{dq}^{123})^{T}$$

Now(23) is $\frac{dv_{dc}}{dt} = \frac{1}{c_{dc}}(q_{n123})^{T}(i_{c123})$ (26)

Applying coordination transformation

$$\frac{dv_{dc}}{dt} = \frac{1}{C_{dc}}(C_{123}^{dq}[q_{ndq}])^{T}(C_{123}^{dq}[i_{dq}]) = \frac{1}{C_{dc}}[q_{ndq}]^{T}[i_{dq}] \tag{27}$$

On the other hand, the two first equations in (24) are written as

$$\frac{d^2}{dt^2}[i_{c12}] = -\frac{R_{PF}}{L_{PF}}\frac{d}{dt}[i_{c12}] - \frac{1}{C_{PF}L_{PF}}[i_{c12}] - \frac{1}{L_{PF}}[q_{n12}]\frac{dv_{dc}}{dt} + \frac{1}{L_{PF}}\frac{d}{dt}[v_{s12}] \tag{28}$$

The reduced matrix can be used

$$C_{dq}^{12} = \sqrt{2}\begin{bmatrix} \cos(\theta - \pi/6) & \sin\theta \\ -\sin(\theta - \pi/6) & \cos\theta \end{bmatrix} \tag{29}$$

It has the following inverse

$$C_{12}^{dq} = \sqrt{\frac{2}{3}}\begin{bmatrix} \cos\theta & -\sin\theta \\ \sin(\theta - \pi/6 & \cos(\theta - \pi/6) \end{bmatrix} \tag{30}$$

Apply this transformation into (28)

$$\frac{d^2}{dt^2}\left[C_{12}^{dq}\left[i_{dq}\right]\right]=-\frac{R_{PF}}{L_{PF}}\frac{d}{dt}\left[C_{12}^{dq}\left[i_{dq}\right]\right]-\frac{1}{C_{PF}L_{PF}}C_{12}^{dq}\left[i_{dq}\right]-\frac{1}{L_{PF}}C_{12}^{dq}\left[q_{ndq}\right]\frac{dv_{dc}}{dt}+\frac{1}{L_{PF}}\frac{d}{dt}\left[C_{12}^{dq}\left[v_{dq}\right]\right] \quad (31)$$

With the following matrix differentiation property

$$\frac{d}{dt}\left[C_{12}^{dq}\left[i_{dq}\right]\right]=C_{12}^{dq}\frac{d}{dt}\left[i_{dq}\right]+\left(\frac{d}{dt}C_{12}^{dq}\right)\left[i_{dq}\right] \quad (32)$$

$$\frac{d^2}{dt^2}\left[C_{12}^{dq}\left[i_{dq}\right]\right]=C_{12}^{dq}\frac{d^2}{dt^2}\left[i_{dq}\right]+\left(\frac{d}{dt}C_{12}^{dq}\right)\left[i_{dq}\right]+\left(\frac{d}{dt}C_{12}^{dq}\right)\frac{d}{dt}\left[i_{dq}\right]+\left(\frac{d^2}{dt^2}C_{12}^{dq}\right)\left[i_{dq}\right] \quad (33)$$

Now the following relation is derived:

$$\frac{d^2}{dt^2}\left[i_{dq}\right]=-\begin{bmatrix}\frac{R_{PF}}{L_{PF}} & -2\omega \\ 2\omega & \frac{R_{PF}}{L_{PF}}\end{bmatrix}\frac{d}{dt}\left[i_{dq}\right]-\begin{bmatrix}-\omega^2+\frac{1}{C_{PF}L_{PF}} & -\omega\frac{R_{PF}}{L_{PF}} \\ \omega\frac{R_{PF}}{L_{PF}} & -\omega^2+\frac{1}{C_{PF}L_{PF}}\end{bmatrix}\left[i_{dq}\right]-\frac{1}{L_{PF}}\left[q_{ndq}\right]\frac{d}{dt}v_{dc}+\frac{1}{L_{PF}}\frac{d}{dt}\left[v_{dq}\right]+\frac{1}{L_{PF}}\begin{bmatrix}0 & -\omega \\ \omega & 0\end{bmatrix}\left[v_{dq}\right] \quad (34)$$

Now the complete model in the d-q frame is obtained from (27) and (34)

$$L_{PF}\frac{d^2 i_d}{dt^2}=-R_{PF}\frac{di_d}{dt}+2\omega L_{PF}\frac{di_d}{dt}-(-\omega^2 L_{PF}+\frac{1}{C_{PF}})i_d+\omega R_{PF}i_q-q_{nd}\frac{dv_{dc}}{dt}+\frac{dv_d}{dt}-\omega v_q$$

$$L_{PF}\frac{d^2 i_q}{dt^2}=-R_{PF}\frac{di_q}{dt}-2\omega L_{PF}\frac{di_d}{dt}-(-\omega^2 L_{PF}+\frac{1}{C_{PF}})i_q-\omega R_{PF}i_d-q_{nq}\frac{dv_{dc}}{dt}+\frac{dv_q}{dt}+\omega v_d$$

$$C_{dc}\frac{dv_{dc}}{dt}=q_{nd}i_d+q_{nq}i_q \quad (35)$$

The model is time invarient during a given switching state.

3.3 HARMONIC CURRENT CONTROL

$$L_{PF}\frac{d^2 i_d}{dt^2}+R_{PF}\frac{di_d}{dt}+(-\omega^2 L_{PF}+\frac{1}{C_{PF}})i_d=2\omega L_{PF}\frac{di_q}{dt}+\omega R_{PF}i_q-q_{nd}\frac{dv_{dc}}{dt}+\frac{dv_d}{dt}-\omega v_q$$

$$L_{PF}\frac{d^2 i_q}{dt^2}-R_{PF}\frac{di_q}{dt}+(-\omega^2 L_{PF}+\frac{1}{C_{PF}})i_q=-2\omega L_{PF}\frac{di_d}{dt}-\omega R_{PF}i_d-q_{nq}\frac{dv_{dc}}{dt}+\frac{dv_q}{dt}+\omega v_d \qquad (36)$$

$$u_d=2\omega L_{PF}\frac{di_q}{dt}+\omega R_{PF}i_q-q_{nd}\frac{dv_{dc}}{dt}+\frac{dv_d}{dt}-\omega v_q$$

$$u_q=-2\omega L_{PF}\frac{di_d}{dt}-\omega R_{PF}i_d-q_{nq}\frac{dv_{dc}}{dt}+\frac{dv_q}{dt}+\omega v_d \qquad (37)$$

Now the transfer function of the model is:

$$\frac{I_d(S)}{U_d(S)}=\frac{1}{L_{PF}S^2+R_{PF}(S)+\frac{1}{C_{PF}}-L_{PF}\omega^2} \qquad (38)$$

Transfer function of the P-I controller is given as

$$G_i(S)=\frac{U_d(S)}{I_d(S)}=\frac{U_q(s)}{I_q(s)}=k_p+\frac{k_i}{S} \qquad (39)$$

The closed loop transfer function of the current loop is

$$\frac{I_q(S)}{I_q'(S)}=\frac{I_d(S)}{I_d'(S)}=\frac{k_p}{L_{PF}}\bullet\frac{S+\frac{k_i}{k_p}}{S^3+\frac{R_{PF}}{L_{PF}}S^2+(\frac{1}{C_{PF}L_{PF}}-\omega^2+\frac{k_P}{L_{PF}})S+\frac{k_i}{L_{PF}}} \qquad (40)$$

The control loop of the current i_q is shown in the fig. below and the control law is

$$q_{nd} = \frac{2\omega L_{PF}\frac{di_q}{dt} + \omega R_{PF} i_q + \frac{d_{vd}}{dt} - \omega v_q - u_d}{\frac{dv_{dc}}{dt}}$$

$$q_{nq} = \frac{2\omega L_{PF}\frac{di_d}{dt} + \omega R_{PF} i_d + \frac{d_{vq}}{dt} - \omega v_d - u_q}{\frac{dv_{dc}}{dt}} \quad (41)$$

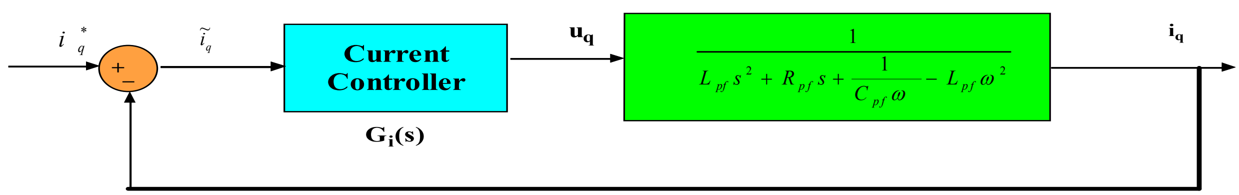


Fig.6. Control loop of the current.

Note that the inputs q_{nd} and q_{nq} consist of a nonlinearity cancellation part and a linear decoupling compensation part.

3.4 REGULATION OF DC VOLTAGE

The active filter produces a fundamental voltage which is in-phase with fundamental leading current of the passive filter. A small amount of active power is formed due to the leading current and fundamental voltage of the passive filter and it delivers to the dc capacitor. Therefore, the electrical quantity adjusted by the dc-voltage controller is consequently i_{q1}^*. To maintain V_{dc}

equal to its reference value, the losses through the active filter's resistive-inductive branches will be compensated by acting on the supply current.

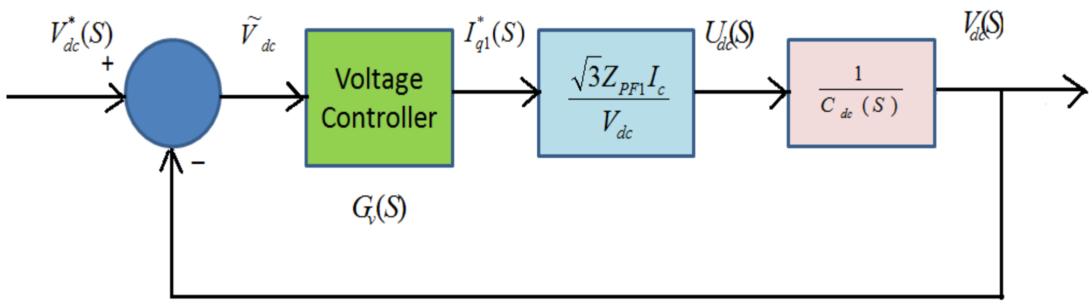


Fig.7 Control loop of the voltage

From (35) we can deduced to

$$C_{dc}\frac{dv_{dc}}{dt} = q_{nq}i_q \tag{42}$$

An equivalent u_{dc} is defined as $u_{dc} = q_{nq}i_q$ (43)

Hence the reactive current of the active filter is

$$i_q = \frac{u_{dc}}{q_{nq}} - \frac{u_{dc}v_{dc}}{q_{nq}v_{dc}} \tag{44}$$

Now assume $q_{nq}v_{dc} \approx v_{Mq}$ and $q_{nd}v_{dc} \approx v_{Md}$

Hence $i_q = \frac{u_{dc} v_{dc}}{v_{Mq}}$ (45)

the q axes active filter voltage V_{Mq} is given by

$$v_{Mq} = -Z_{PF1} i_{q1}^{*}$$

Where Z_{PF1} is the impedance of the passive filter at 50 Hz and i_{q1}^{*} is a dc component.

The control effort of the dc-voltage loop is

$$i_{q1}^{*} = \frac{v_{dc}}{-Z_{PF1} i_q} u_{dc} \quad (46)$$

The three phase filter current are expressed as

$$\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = \sqrt{\frac{2}{3}} i_q \begin{bmatrix} -\sin \theta \\ -\sin \left(\theta - \frac{2\pi}{3} \right) \\ -\sin \left(\theta - \frac{2\pi}{3} \right) \end{bmatrix}$$

(47)

The fundamental filter rms current I_c is given by

$$I_C = \frac{i_q}{\sqrt{3}} \quad (48)$$

The laplace form of the control effort can be derived as follows:

$$i_{q1}^{*}(s)=\frac{V_{dc}}{\sqrt{3}Z_{PF1}I_{C}}U_{dc}(s) \tag{49}$$

The outer control loop of the dc voltage is shown in Fig. To regulate dc voltage V_{dc}, the error $\widetilde{v}_{dc}=v_{dc}^{*}-v_{dc}$ is passing through a P-I type controller given by

$$u_{dc}=k_{1}\widetilde{v}_{dc}+k_{2}\int\widetilde{v}_{dc}dt \tag{50}$$

hence the closed loop transfer function is

$$\frac{V_{dc}(s)}{V_{dc}^{*}(s)}=2\xi\omega_{nv}\frac{s+\frac{w_{nv}}{2\xi}}{s^{2}+2\xi\omega_{nv}s+\omega_{nv}^{2}} \tag{51}$$

Where ω_{nv} is the outer loop natural angular frequency and ζ is the damping factor.

The transfer functions of Fig. is

$$\frac{V_{dc}(S)}{V_{dc}^{*}(S)}=\frac{\frac{\sqrt{3}Z_{PF1}k_{1}I_{C}}{V_{dc}C_{dc}}(S)+\frac{\sqrt{3}Z_{PF1}k_{2}I_{C}}{V_{dc}C_{dc}}}{S^{2}+\frac{\sqrt{3}Z_{PF1}k_{1}I_{C}}{V_{dc}C_{dc}}(S)+\frac{\sqrt{3}Z_{PF1}k_{2}I_{C}}{V_{dc}C_{dc}}} \tag{52}$$

The proportional k_1 and integral k_2 gains are then obtained as:

$$k_{1}=2\xi\omega_{nv}\left(\frac{V_{dc}C_{dc}}{\sqrt{3}Z_{PF1}I_{C}}\right)$$

$$k_{2}=\omega_{nv}^{2}\left(\frac{V_{dc}C_{dc}}{\sqrt{3}Z_{PF1}I_{C}}\right) \tag{53}$$

3.5 CONCLUSION

This chapter elaborated on modeling of shunt hybrid power filter. The transformation of a-b-c to d-q reference frame is described. How the harmonic current is controlled and DC voltage is regulated, that is described in this chapter.

Chapter 4

CONTROLLER DESIGN

4.1 INTRODUCTION

In distributed system the harmonic current is present in a nonlinear load .By using hybrid filter we can reduced the load harmonics. But only hybrid filter is not sufficient to reduce the total harmonics of the load. Hence some controller is required to more reduce the harmonics. Different controllers are present to reduce the THD. In this chapter P-I controller and hysteresis controller are designed to compensate the load harmonics.

4.2 P-I CONTROLLER

In Fig. the three phase supply currents I_{SA} , I_{SB}, I_{SC} are measured and transformed into synchronous reference frame (d-q) axes rotating at the fundamental angular speed. Power p and q contain two components i.e. dc and ac. A dc components arising from the fundamental component of the source current, and an ac component due to its harmonic components. The ac components i_{dh}, i_{qh} are extracted by two high pass filters and then, the harmonic component of the source current are obtained by applying the inverse transformation. To provide the inverter power losses and to maintain the DC voltage with in desired value, a dc component P_{Loss} is added to the ac component of the imaginary power. It is generated by comparing the DC capacitor voltage with its reference value and applying the error to a P-I controller. To generate the required voltage command for the active filter inverter a d-q to a-b-c transformation is applied to convert the inverter voltage command back to the three phase quantities. The reference voltage of the active power filter is achieved by multiplying ac component of the source current in gain k_h as $v^*_{AF} = k_h i_{sh}$.

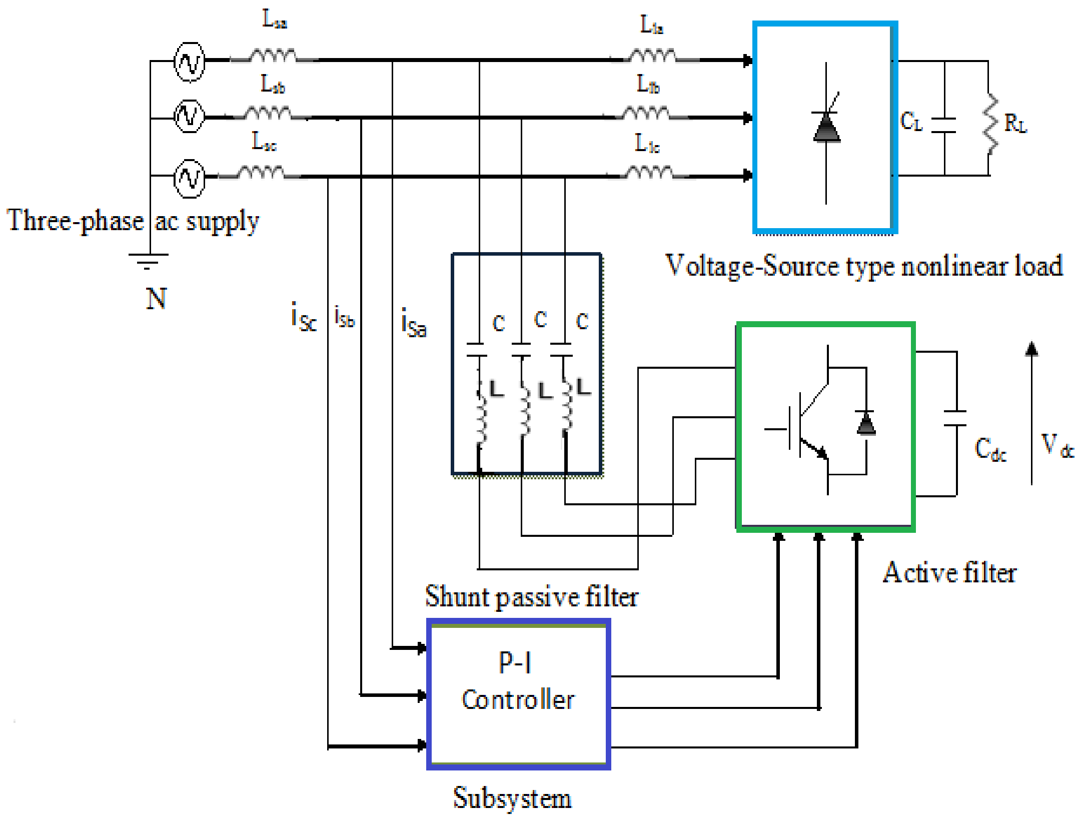


Fig.8 Schematic diagram of SHPF with P-I controller

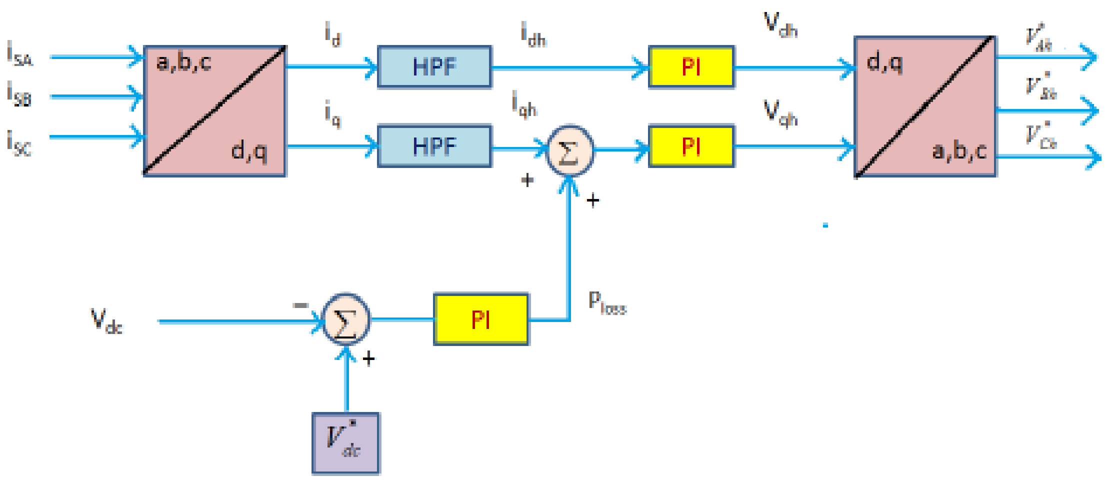


Fig.9 Block diagram of the Subsystem of P-I Controller

4.3 HYSTERESIS CONTROLLER

The load current is supplied to RMS block and PLL block. We are getting the fundamental frequency of the load current from the PLL block. This current is getting multiplied with the RMS value of the load current and the resulting current is subtracted from the load current. Hence we are getting the harmonics current. This harmonic current is fed to the hysteresis block as a reference current (i_{ref}) . The filter current is also fed to the hysteresis block as measured current (i_{meas}). In the hysteresis block the i_{meas} is subtracted from the i_{ref} and feeding to hysteresis band, from where we are getting the switching pulses of the inverter to provide the inverter power losses and to maintain the DC voltage within its desired value.

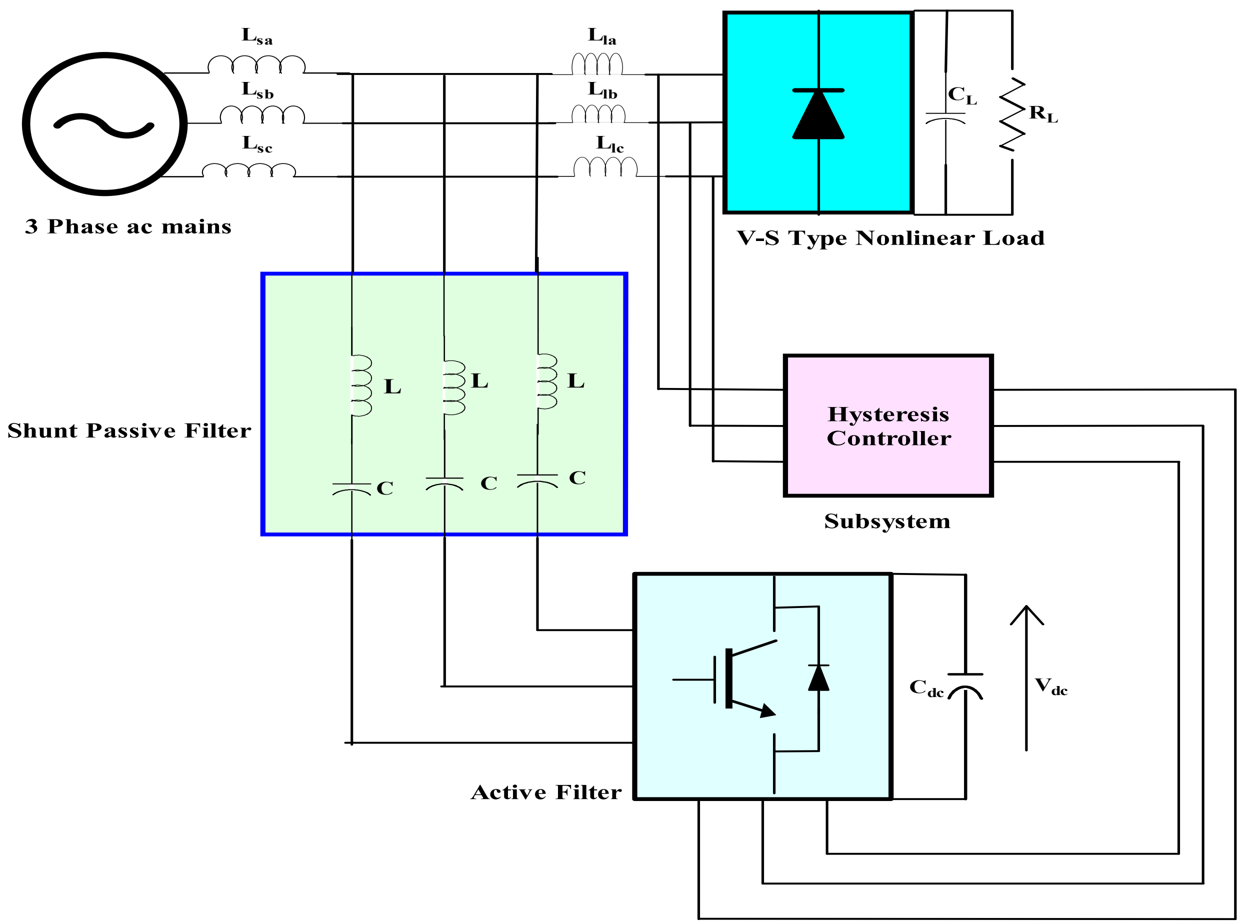


Fig.10 Schematic diagram of SHPF with Hysteresis Controller

4.4 CONCLUSION

In this chapter the hysteresis controller and P-I controller are designed and described how the load harmonics is compensated. By using two different types of controller we can got the comparative study of both the controller.

Chapter 5

SIMULATION RESULTS AND DISCUSSION

5.1 INTRODUCTION

The shunt hybrid power filter which is connected to a voltage source type non-lonear load is simulated by using MATLAB/SIMULINK environment. The scheme is first simulated without any filter to find out the THD of the supply current. Then it is simulated with the hybrid filter to observe the difference in THD of supply current. Simulation is also carried out with hysteresis controller and P-I controller to find out the comparative study of the THD of the supply current.

5.2. SIMULATION RESPONSE OF VOLTAGE SOURCE TYPE-NONLINEAR LOAD

5.2.1 SIMULATION RESPONSE WITHOUT FILTER

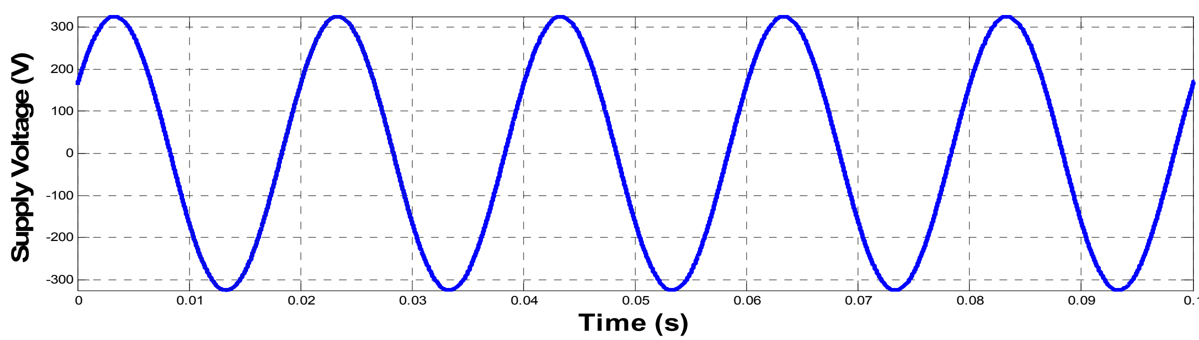


Fig.11 Wave forms of Supply Voltage (V) without filter.

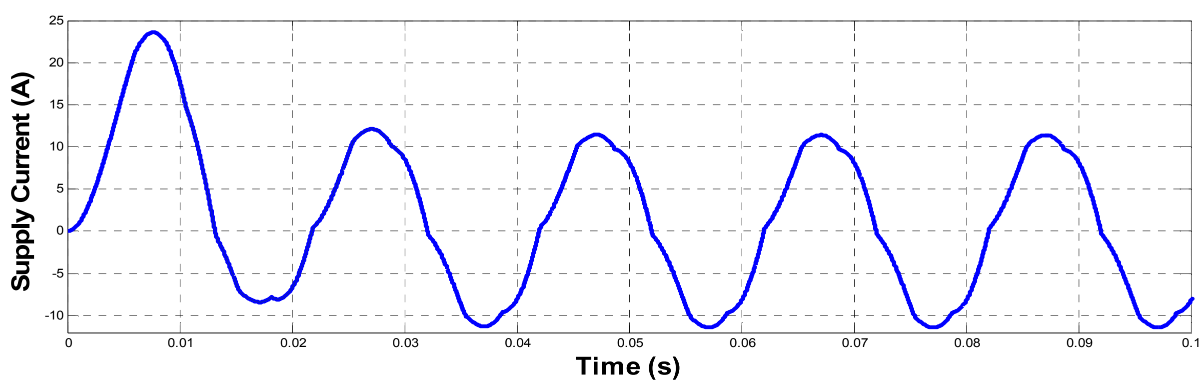
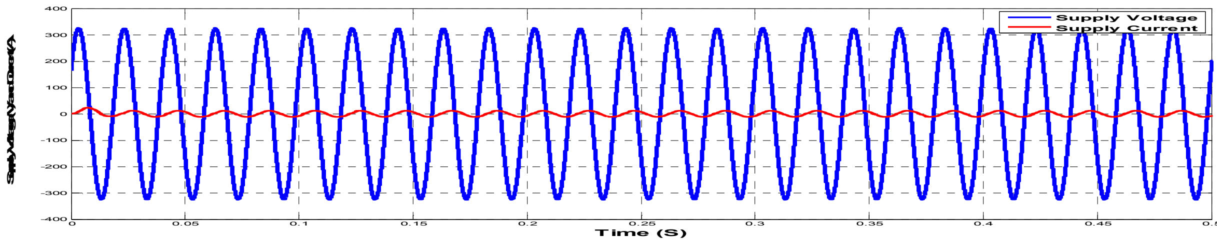


Fig. 12. Wave forms of Supply Current (A) without filter



.Fig.13 Wave forms of Supply Voltage (V) and Current (A) without filter.

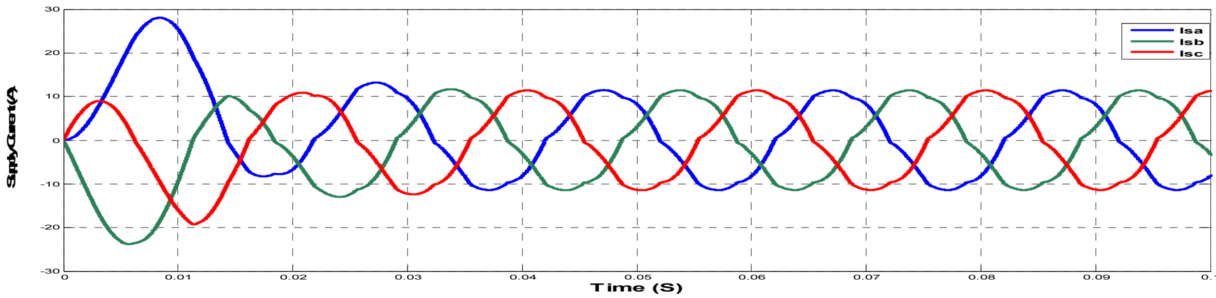


Fig.14 Wave forms of 3-Phase Supply Current (A) Without Filter

Fig. 11 shows the supply voltage, Fig.12 shows the supply current without filter. Fig.13 shows the supply voltage and current without filter and we can see that the current is not in phase with the voltage.

5.2.2 SIMULATION RESPONSE WITH HYBRID FILTER

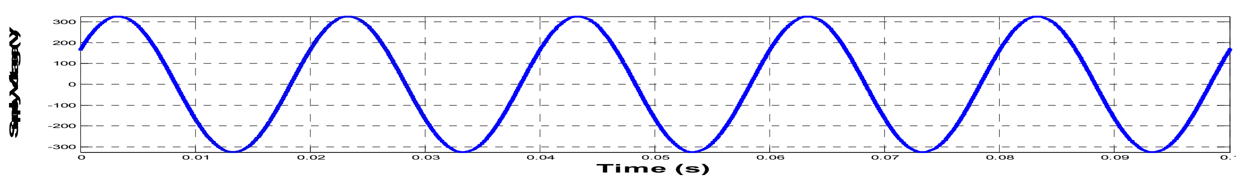


Fig.15 Wave forms of Supply Voltage (V) with hybrid filter.

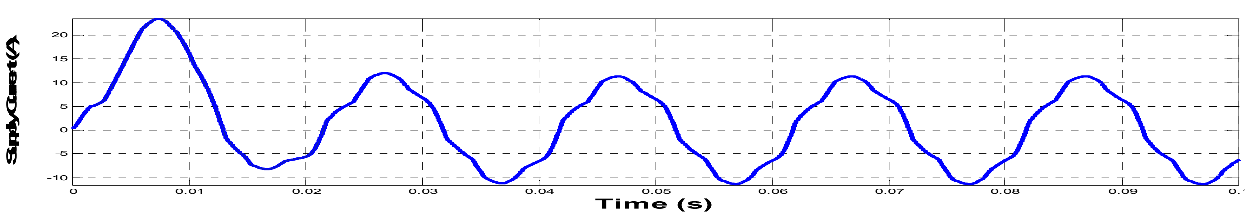


Fig.16 Wave forms of Supply Current (A) with hybrid filter.

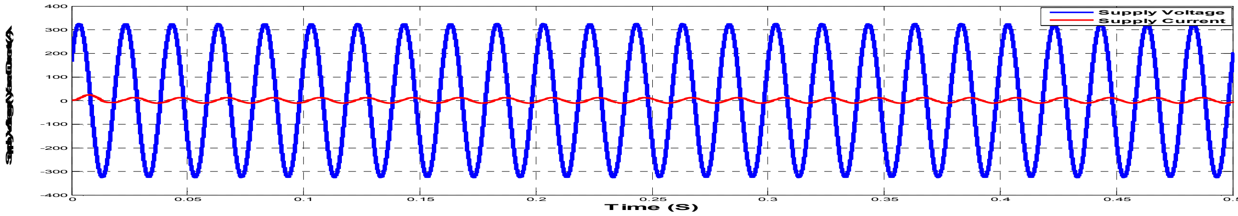


Fig.17 Wave forms of Supply Voltage and Current with hybrid filter.

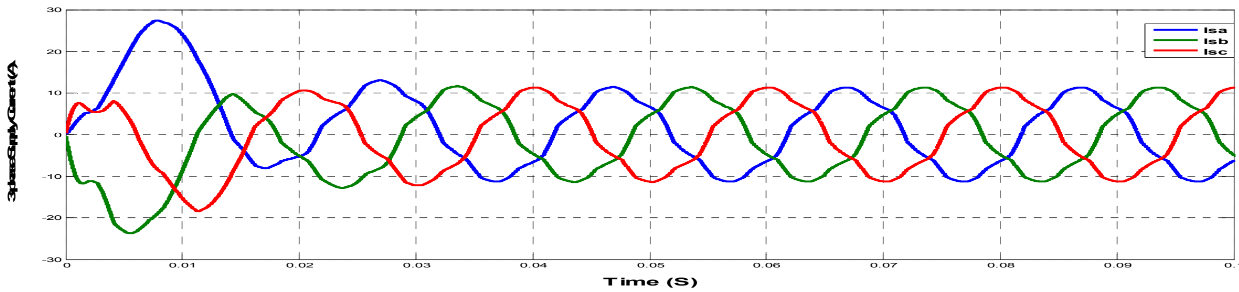


Fig. 18 Wave forms of 3-P hase Supply Current (A) With hybrid Filter

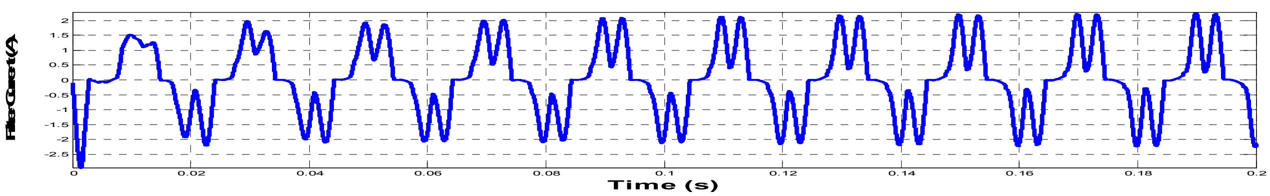


Fig.19 Wave forms of filter Current (A) With hybrid Filter

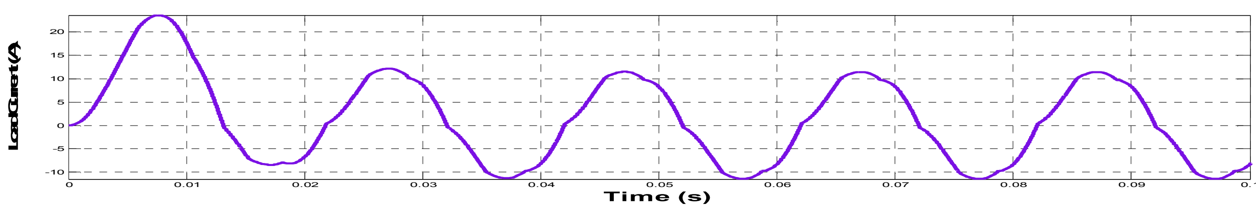


Fig.20 Wave forms of Load Current (A) with hybrid filter.

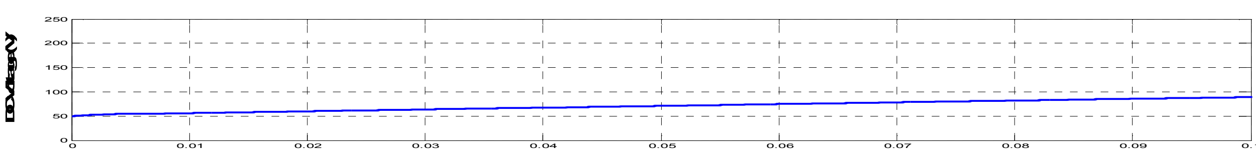


Fig.21 Wave forms of DC Voltage (V) with hybrid filter

Fig.15-Fig.21 represents the simulation responces by using hybrid filter.Here we can see that in Fig. 15 the supply current harmonic is quite reduced, but in Fig.16 the current is not in phase with the voltage.

5.2.3 SIMULATION RESPONSE USING HYSTERESIS CONTROLLER

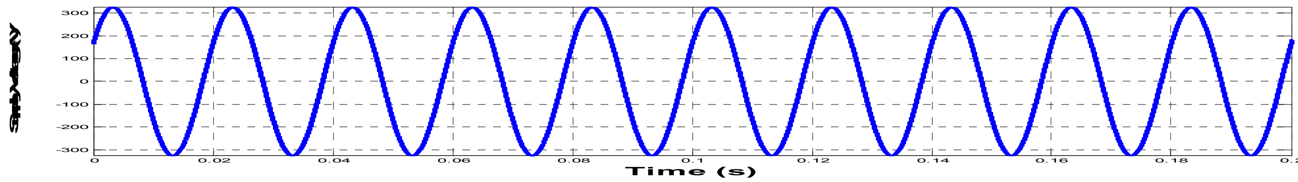


Fig.22 Wave forms of Supply Voltage (V) with hysteresis controller.

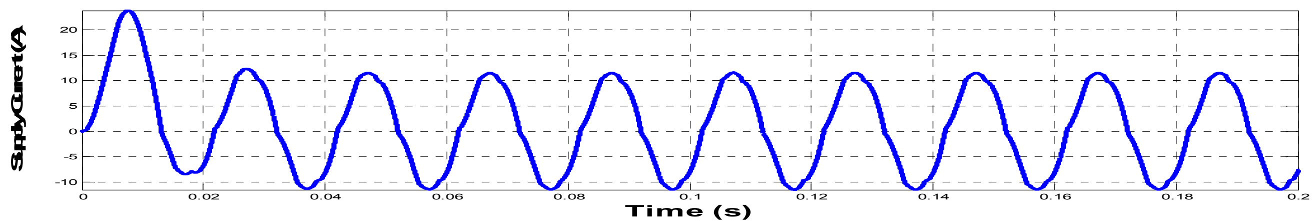


Fig.23 Wave forms of Supply Current (A) with hysteresis controller

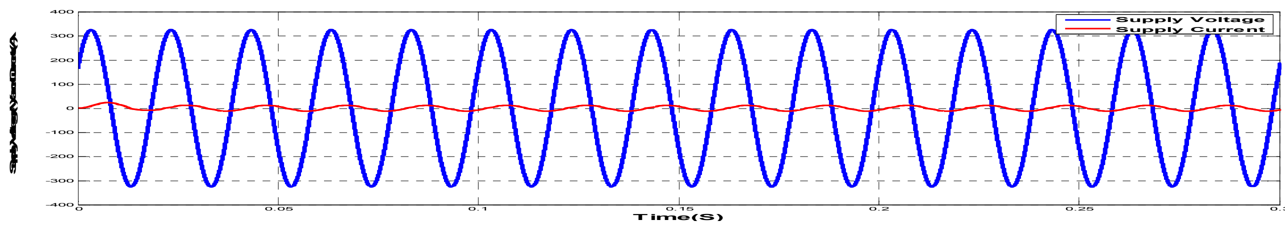


Fig.24 Wave forms of Supply Voltage and Current with hysteresis controller

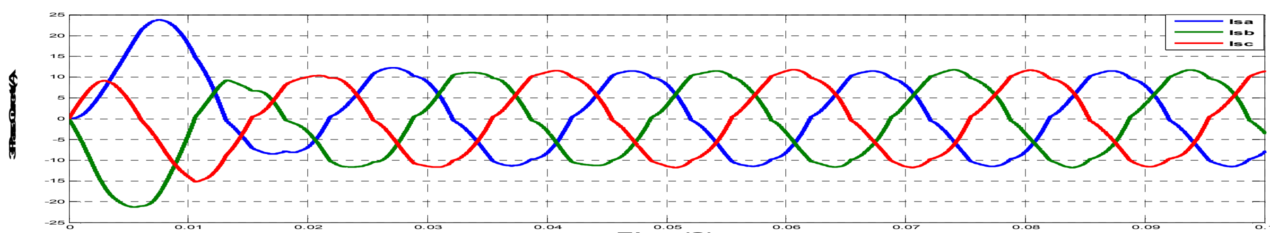


Fig.25 Wave forms of 3-Phase Supply Current (A) With hysteresis controller

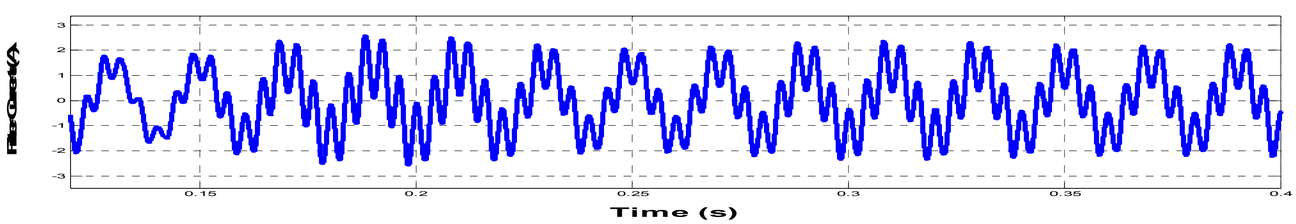


Fig.26 Wave forms of Filter Current (A) with hysteresis controller

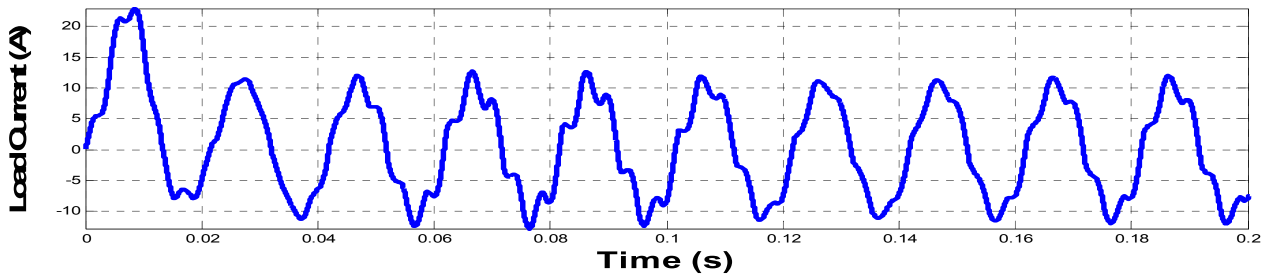


Fig.27 Wave forms of Load Current (A) with hysteresis controller

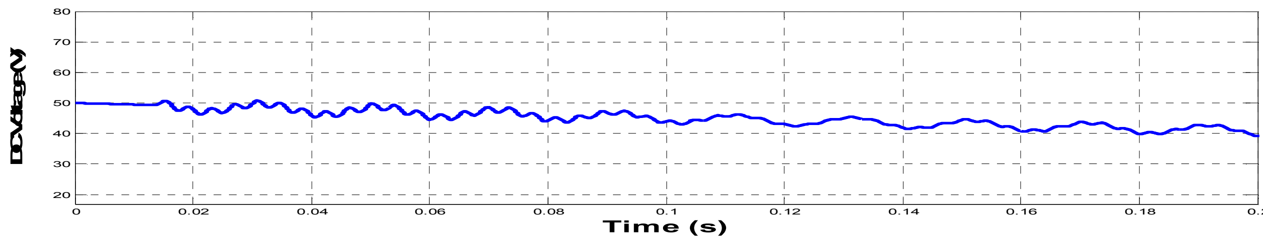


Fig.28 Wave forms of DC Voltage (V) with hysteresis controller

Fig.22 –Fig.28 represents the simulation responces by using hysteresis controller. We can see in Fig. 23 that the supply current harmonic is reduced as compare to hybrid filter but still in Fig. 24 the current is not in phase with the voltage.

5.2.4 SIMULATION RESPONSE USING P-I CONTROLLER

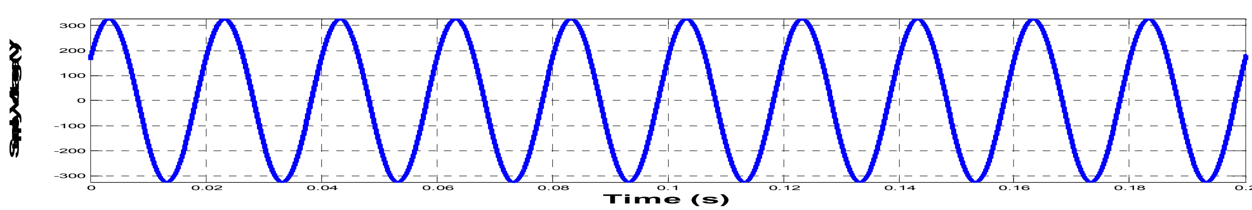


Fig.29 Wave forms of Supply Voltage (V) with P-I controller.

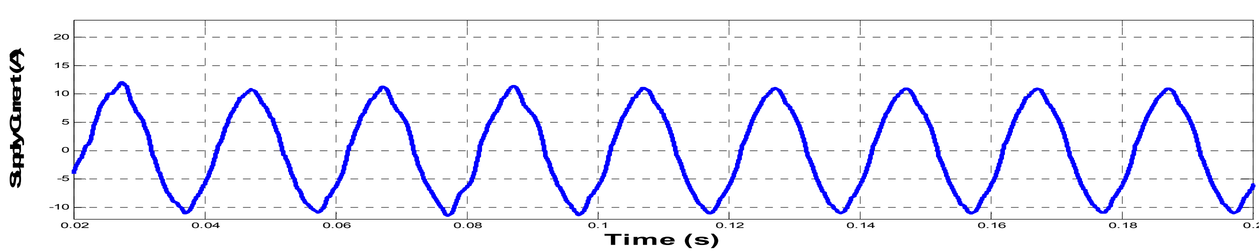


Fig.30 Wave forms of Supply Current (A) with P-I controller

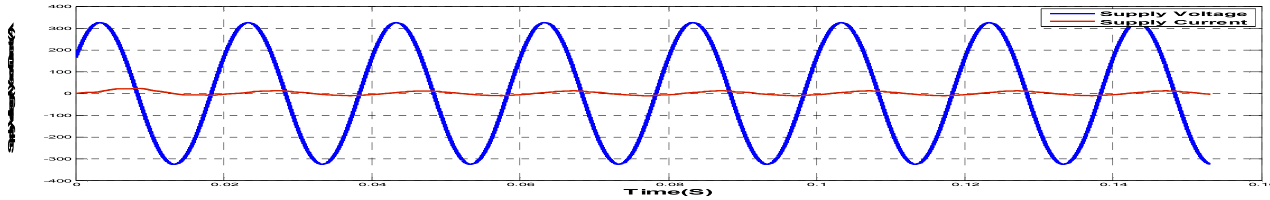


Fig.31 Wave forms of Wave forms of Supply Voltage and Current with P-I controller

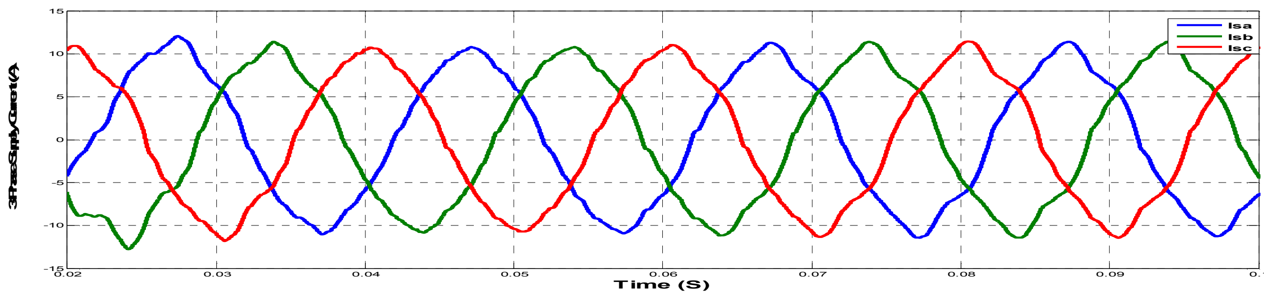


Fig.32 Wave forms of 3-P hase Supply Current (A) With P-I controller

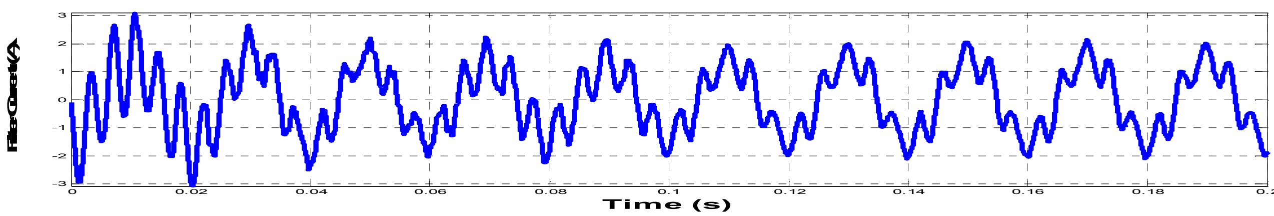


Fig.33 Wave forms of Filter Current (A) with P-I controller

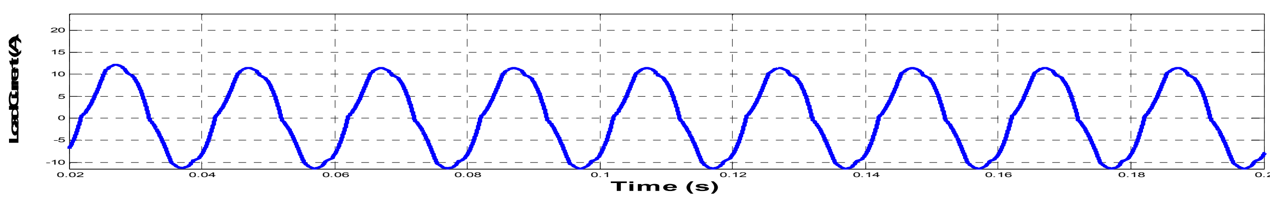


Fig.34 Wave forms of Load Current (A) P-I controller

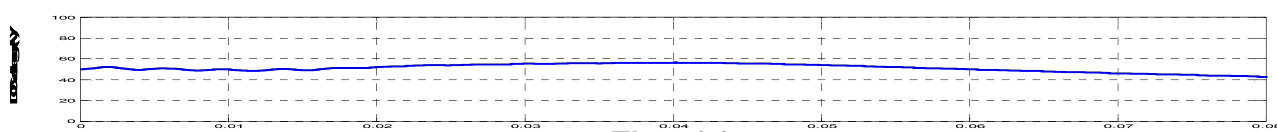


Fig.35 Wave forms of DC Voltage (V) with P-I controller

Fig.29 –Fig.35 represents the simulation responces by using P-I controller. Here we can see that in Fig.30 the supply current harmonic is reduced, but Fig. 31 the current is quite in phase with the voltage.

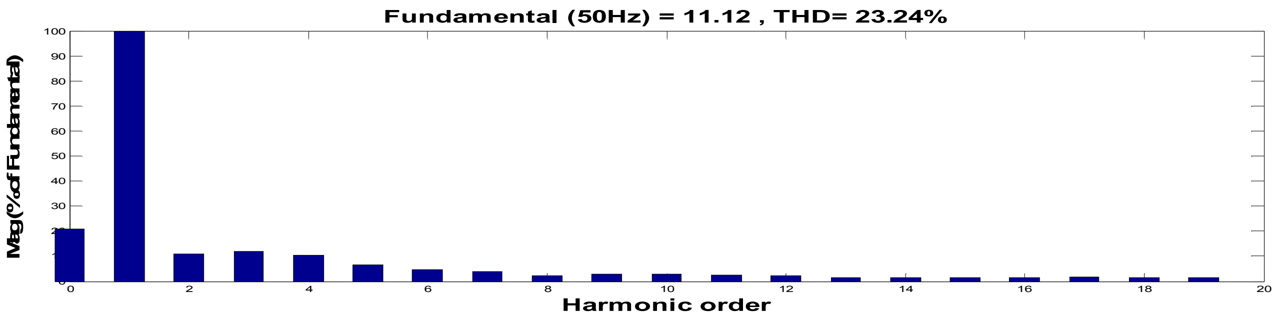


Fig. 36 THD (%) of the supply Current without filter

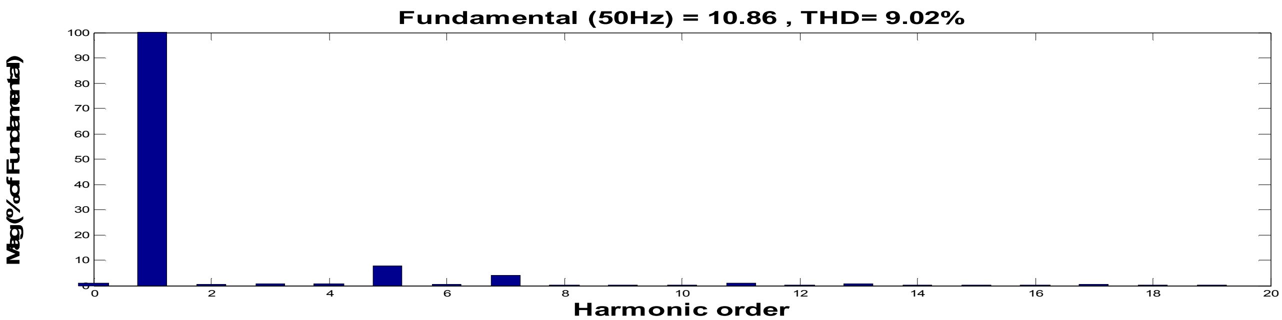


Fig.37 THD (%) of the supply Current with hybrid filter

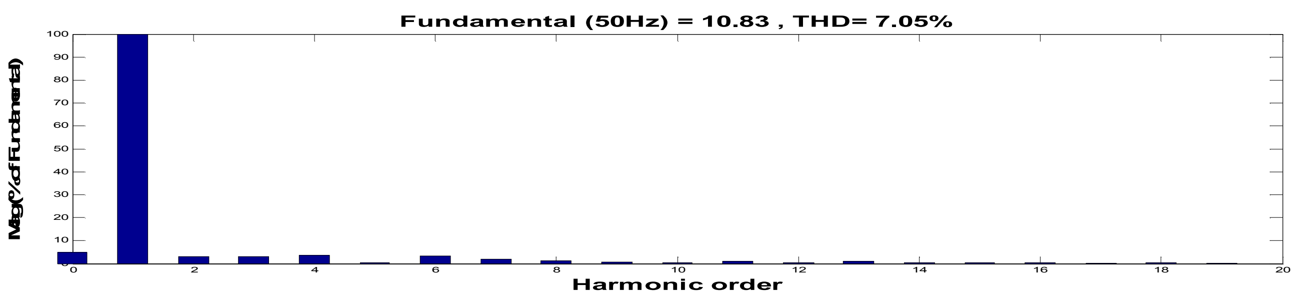


Fig.38 THD (%) of the supply Current with hysterisis controller

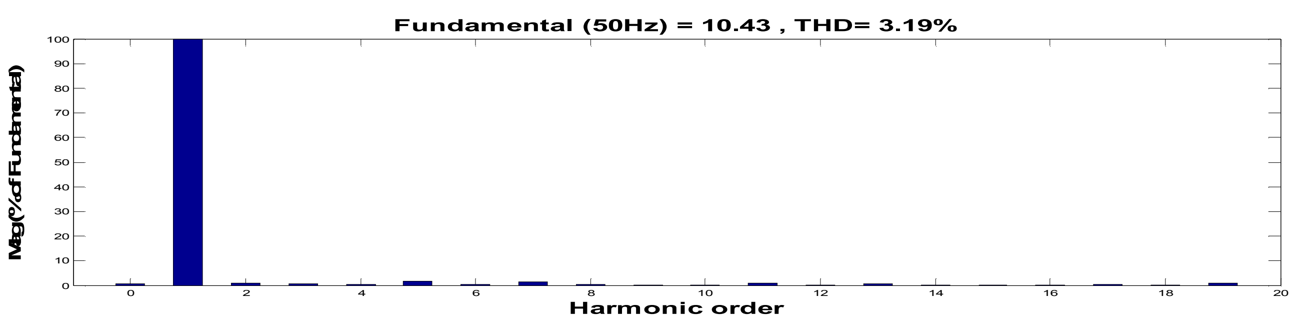


Fig.39 THD (%) of the supply Current with P-I controller.

5.3 SIMULATION RESPONCES OF CURRENT SOURCE TYPE- NONLINEAR LOAD

5.3.1 SIMULATION RESPONCES WITHOUT FILTER

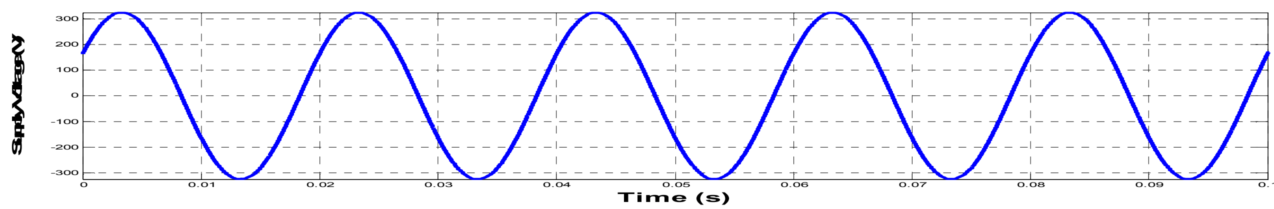


Fig.40 Wave forms of Supply Voltage (V) without filter.

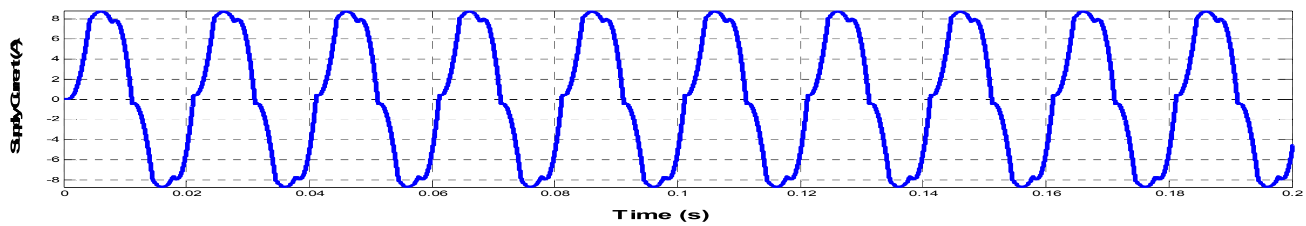


Fig.41 Wave forms of Supply Curent without filter

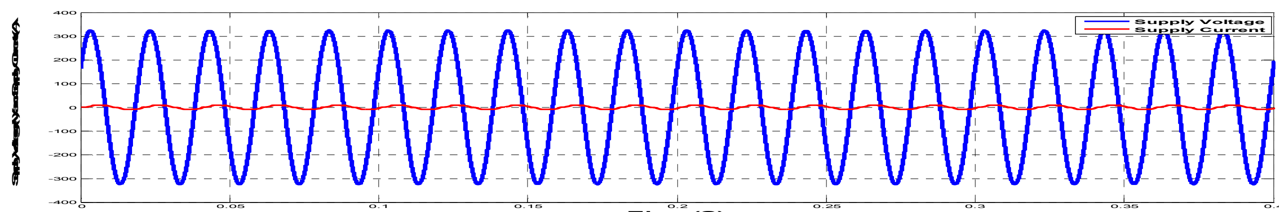


Fig.42 Wave forms of Supply Voltage (V) and Current (A) without filter

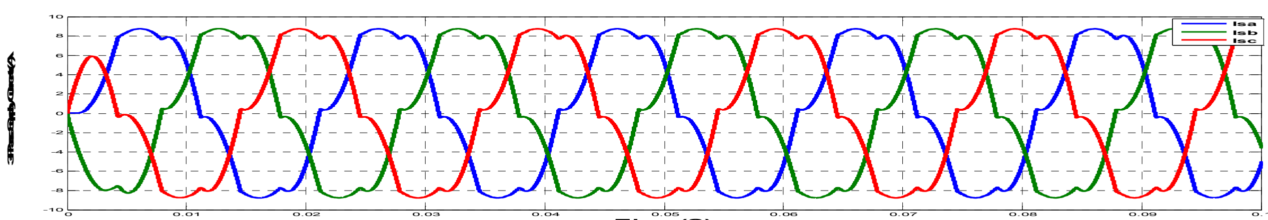


Fig.43 Wave forms of 3-Phase supply current without filter

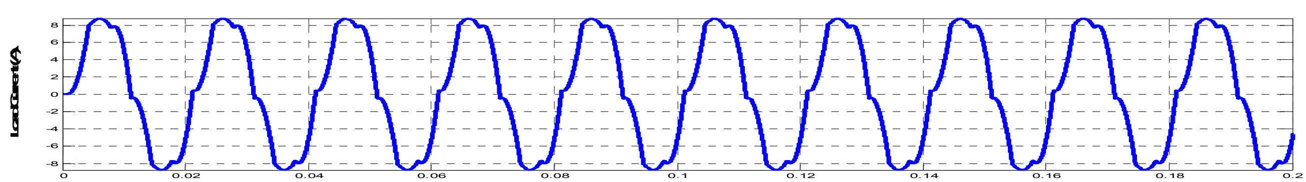


Fig.44 Wave forms of Load Curent (A) without filter

In current source type of nonlinear load the current harmonics is represented in Fig.41. It is very distorted.The THD is 11.27% in open loop response.

5.3.2 WITH HYBRID FILTER

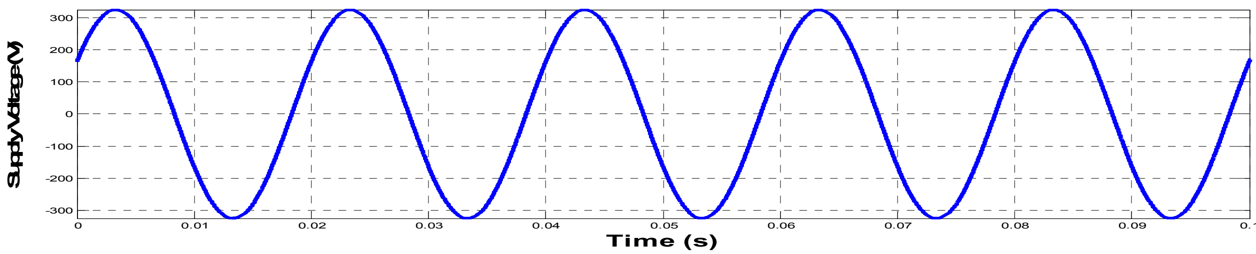


Fig.45 Wave forms of Supply Voltage (V) without filter.

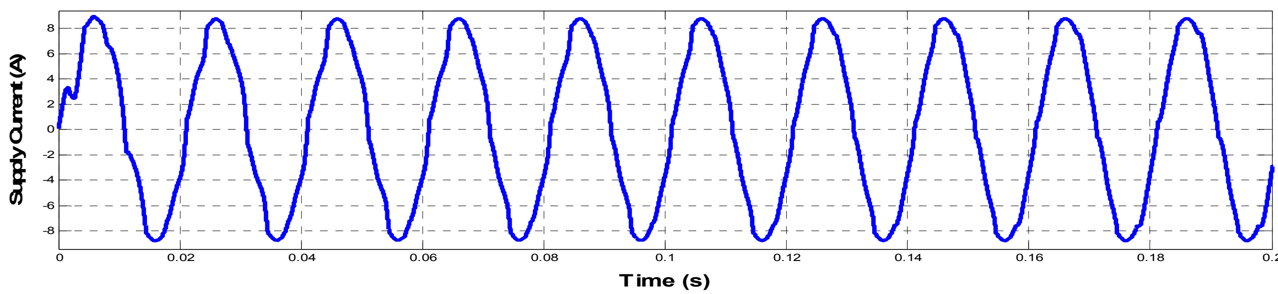


Fig.46 Wave forms of Supply Current with hybrid filter with hybrid filter.

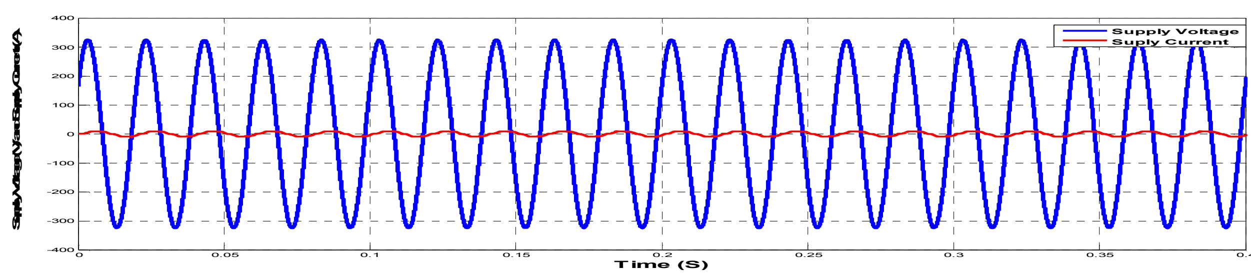


Fig.47 Wave forms of Supply Voltage (V) and Current (A) with hybrid filter.

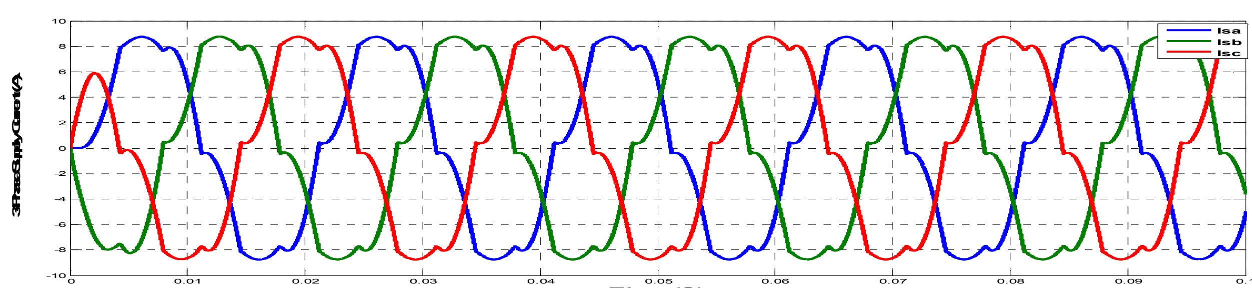


Fig.48 Wave forms of 3-Phase supply current with hybrid filter.

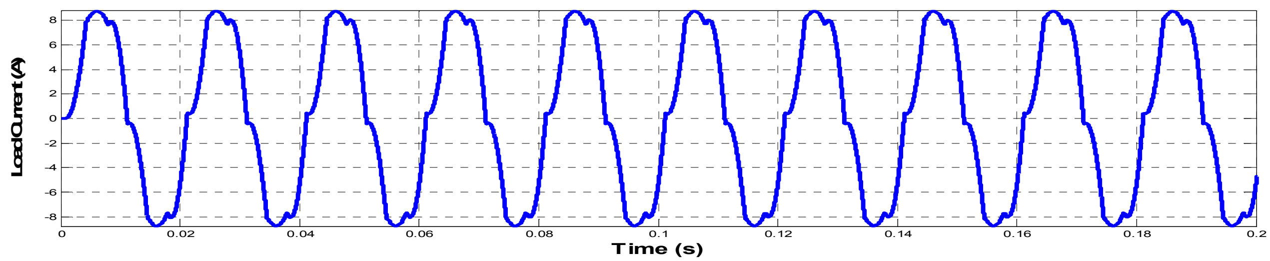


Fig.49 Wave forms of Load Current (A) with hybrid filter.

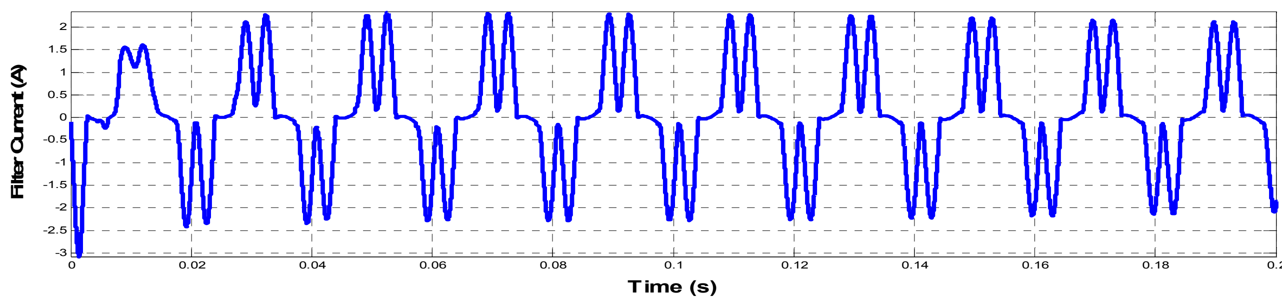


Fig.50 Wave forms of Filter Current (A) with hybrid filter.

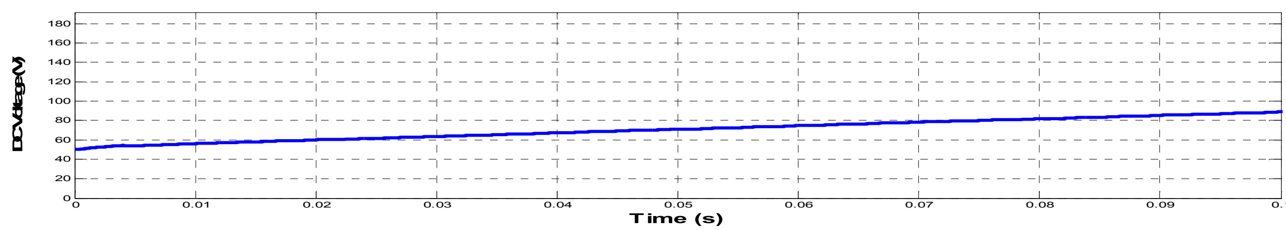


Fig.51 Wave forms of DC Voltage with hybrid filter.

By using hybrid filter the current harmonics is reduced as compare to open loop response.The voltage and current waveforms is represented in Fig.47. The THD is reduced to 9.43%.

5.3.3 WITH HYSTERESIS CONTROLLER

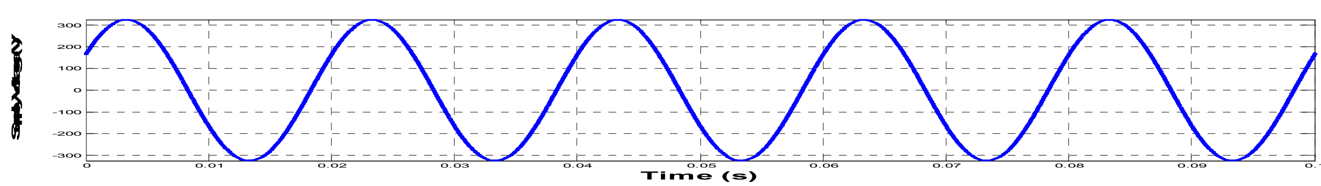


Fig.52 Wave forms of Supply Voltage (V) with hysteresis controller.

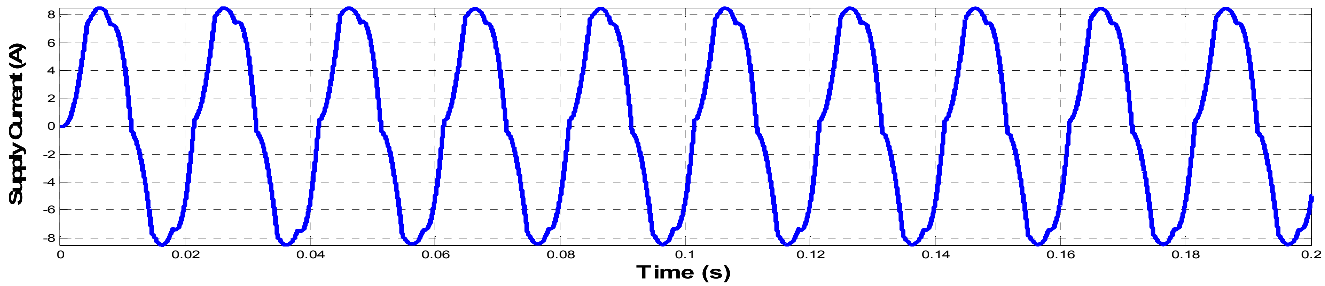


Fig.53 Wave forms of Supply Current with hysteresis controller.

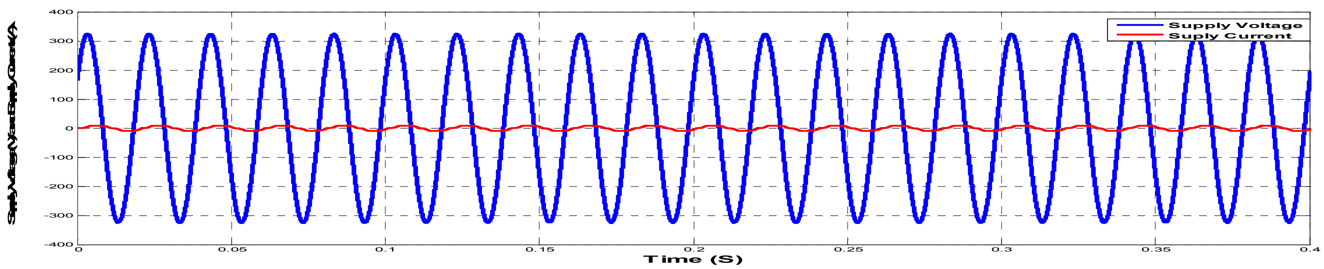


Fig.54 Wave forms of Supply Voltage (V) and Current (A) with hysteresis controller.

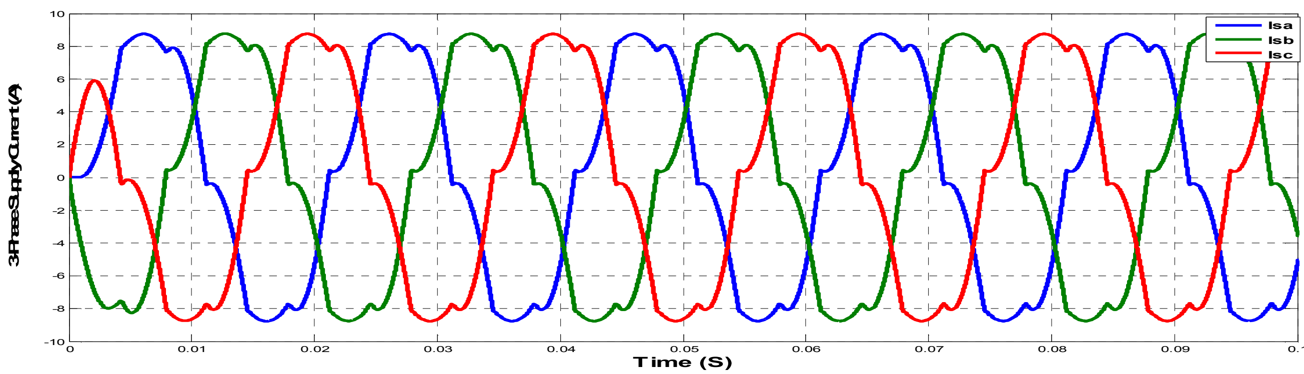


Fig.55 Wave forms of 3-Phase supply current with hysteresis controller.

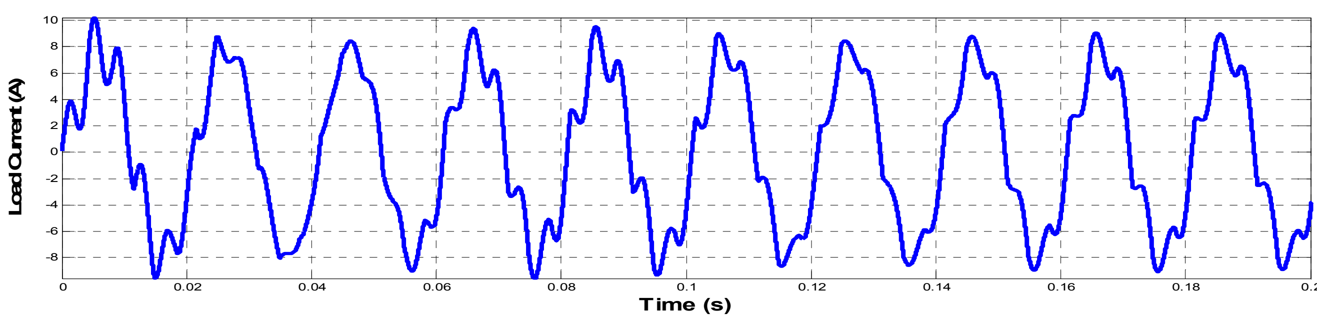


Fig.56 Wave forms of Load Current with hysteresis controller.

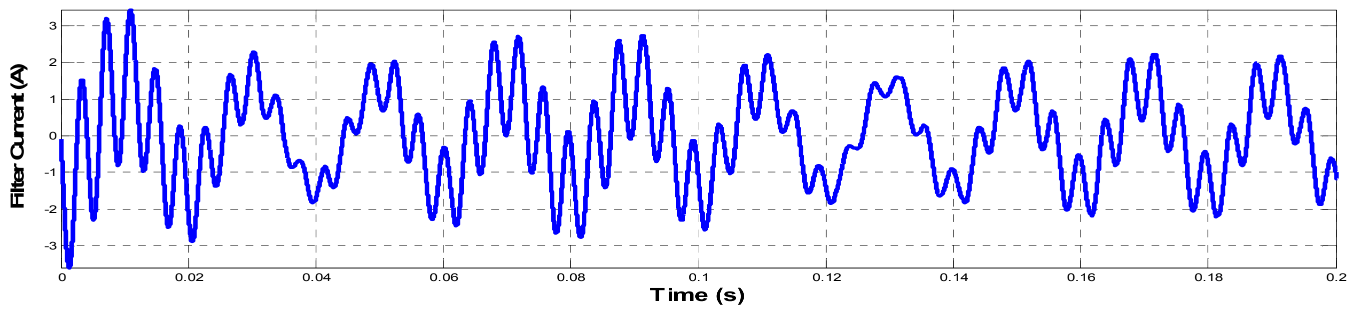


Fig.57 Wave forms of Filter Current (A) with hysteresis controller.

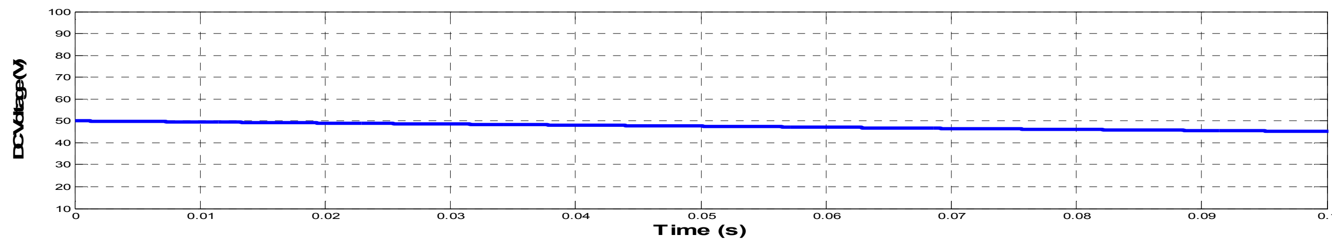


Fig.58 Wave forms of DC Voltage with hysteresis controller.

By using hysteresis controller the current harmonics is reduced as compare to hybrid filter.The voltage and current waveforms is represented in Fig.54. The THD is reduced to 8.49%.

5.3.4 WITH P-I CONTROLLER

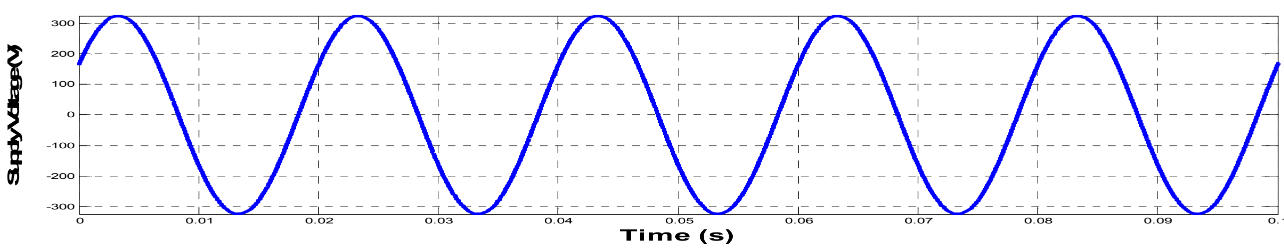


Fig.59 Wave forms of Supply Voltage (V) with P-I controller.

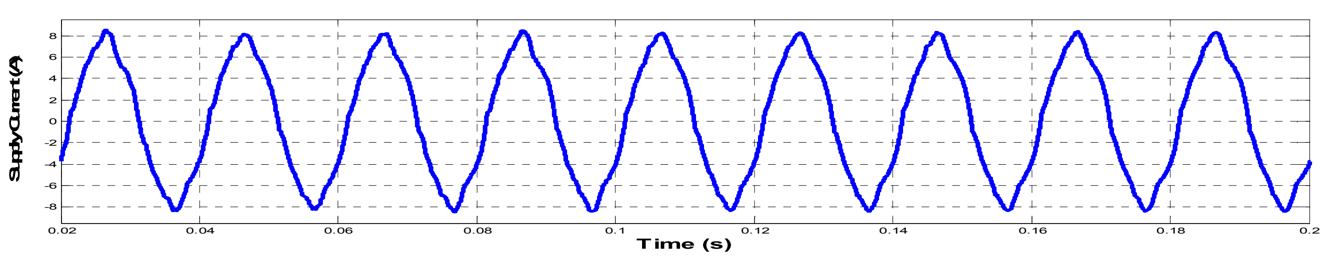


Fig.60 Wave forms of Supply Current with P-I controller.

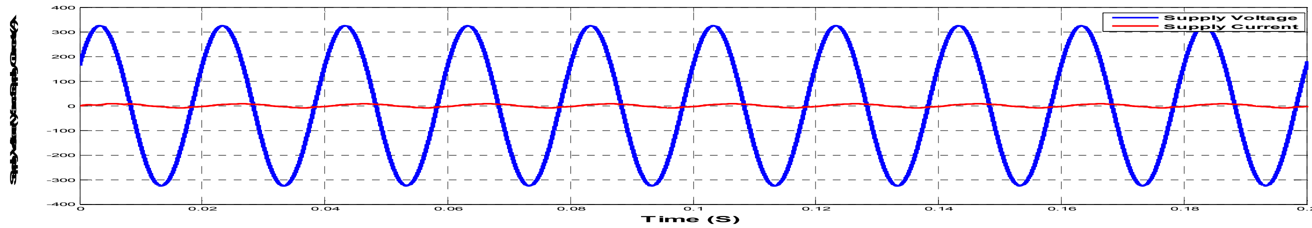


Fig.61 Wave forms of Supply Voltage (V) and Current (A) with P-I controller.

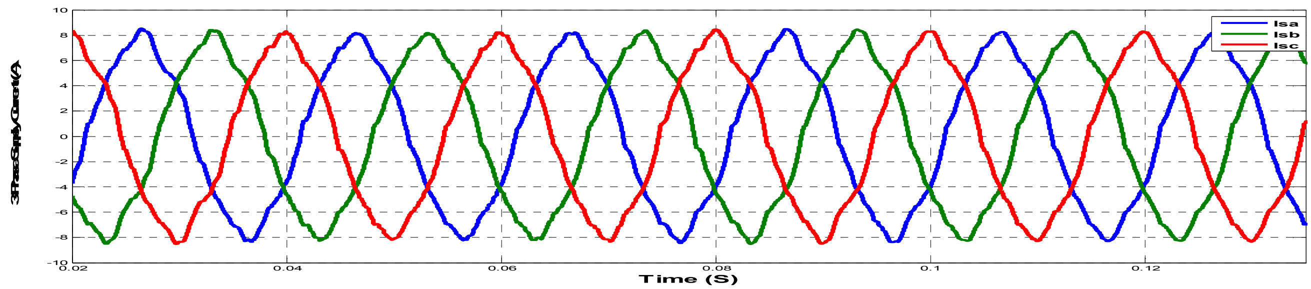


Fig.62 Wave forms of 3-Phase supply current with P-I controller.

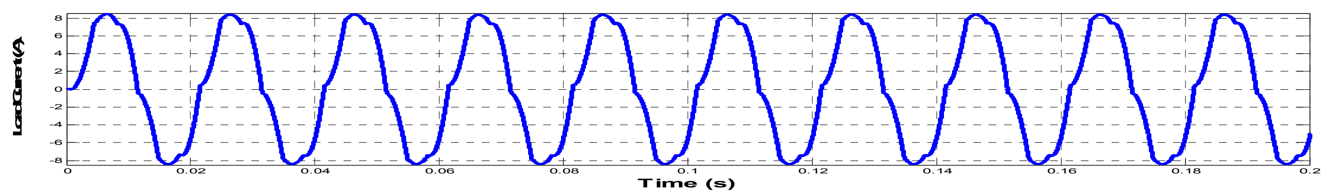


Fig.63 Wave forms of Load Current (A) with P-I controller.

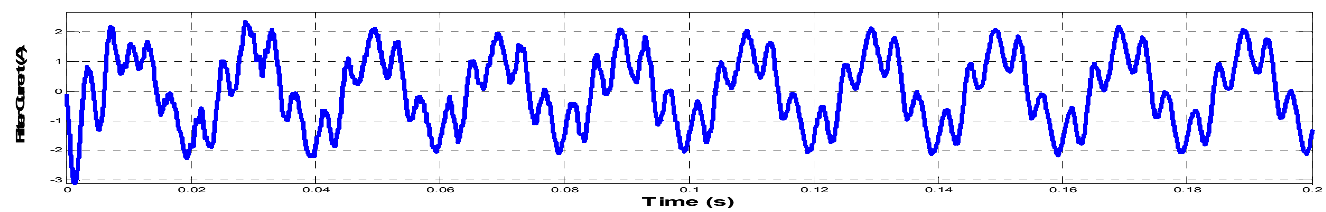


Fig.64 Wave forms of Filter Current (A) with P-I controller.

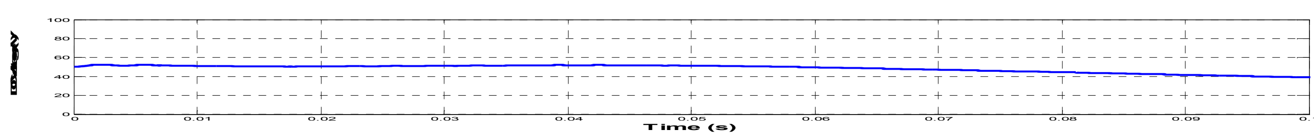


Fig.65 Wave forms of DC Voltage (V) with P-I controller.

By using P-I controller the current harmonics is reduced as compare to hysteresis controller. The voltage and current waveforms is represented in Fig.59-61. The THD is reduced to 4.54% by using P-I controller.

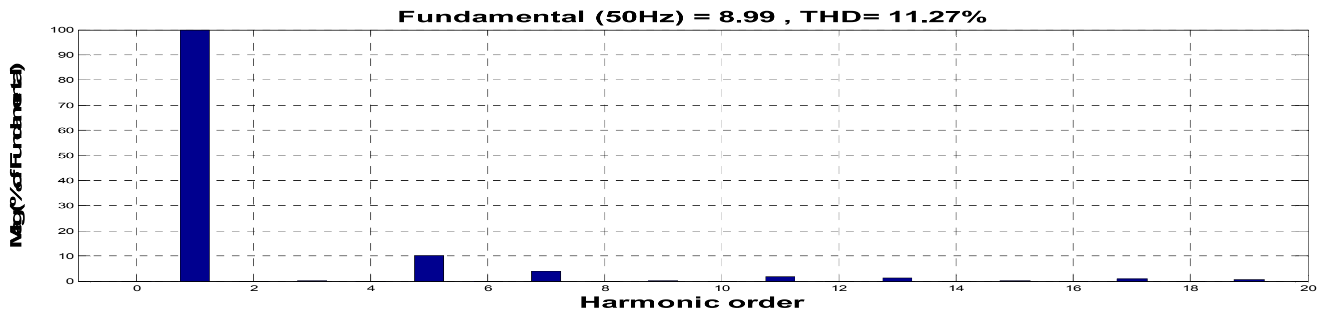


Fig. 66 THD (%) of the supply Current without filter

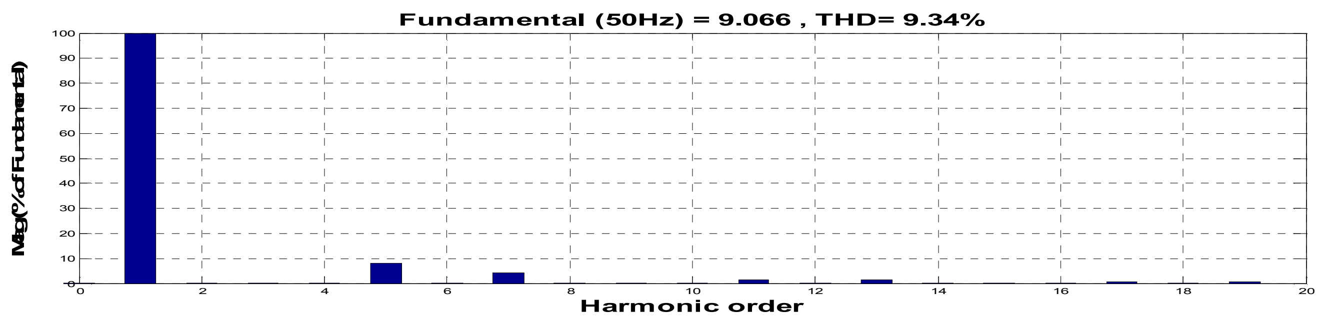


Fig.67 THD (%) of the supply Current with hybrid filter

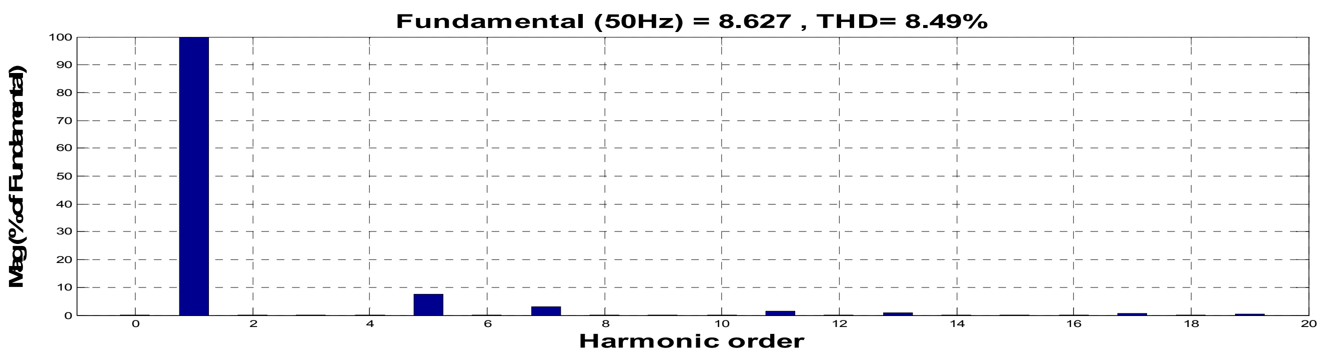


Fig.68 THD (%) of the supply Current with hysterisis controller

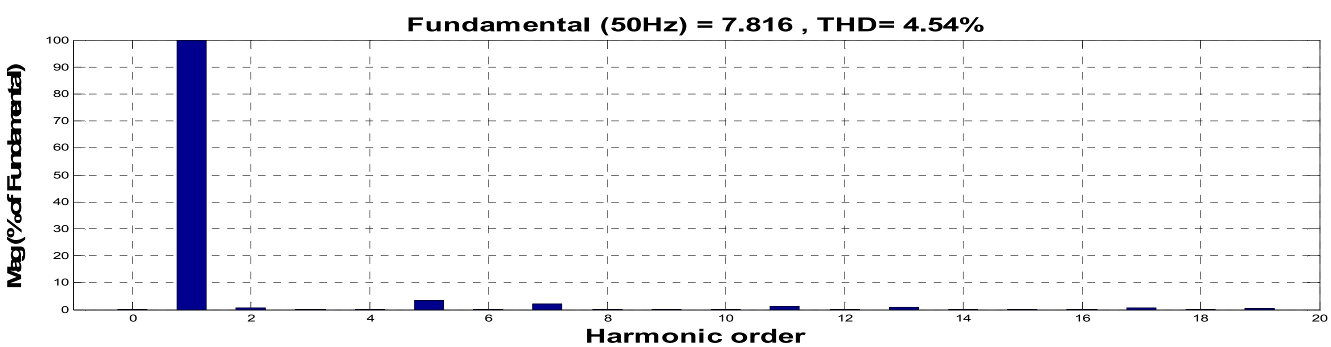


Fig.69 THD (%) of the supply Current with P-I controller.

The THD for different cases are represented in Fig.66 –Fig.69

Chapter 6

CONCLUSION AND SCOPE OF FUTURE WORK

Conclusion

Scope of Future Work

6.1 CONCLUSION

This project work presents design of shunt passive filter and shunt hybrid power filter for a distribution system.The hybrid filter reduces the harmonics as compare to open loop response. This hybrid filter is tested and verified using MATLAB program. A P-I controller and hysteresis controller is implemented for three phase shunt hybrid power filter. The P-I controller and hysteresis controller extracts the reference current from the distorted line current and hence improve the power quality parameters such as harmonic current and reactive power due to non-linear load. Here two types of non-linear load i.e. voltage souurce type of non-linear load and current source type of non-linear load is implementd. The harmonic current control and DC-capacitor voltage can be regulated under these two non-linear loads. We obtained it from the simulation responces. The shunt hybrid power filter is verified with the simulation results. The performance of the P-I controller and hysteresis controller is verified with the simulation results. Hence we obtained a comparative results by using this two controllers. The comparative simulation results for both type of non-linear load is presented in the table-2 and table-3

TABLE_2

Voltage Source Type Of Nonlinear Load

Currents	THD (%) before Compensation	THD (%) after compensation		
	Without filter	With hybrid filter	With hysteresis controller	With P-I controller
Supply current	23.24	8.51	7.05	3.19
Load current	23.24	11.11	9.77	5.93
Filter current	Nil	43.14	34.46	44.90

TABLE-3

Current Source Type Of Nonlinear Load

Currents	THD (%) before Compensation	THD (%) after compensation		
	Without filter	With hybrid filter	With hysteresis controller	With P-I controller
Supply current	11.27	9.34	8.29	4.54
Load current	11.27	10.98	9.01	9.20
Filter current	Nil	49.41	54.63	49.82

Hence we got the simulation responses for voltage source type of nonlinear load and current source type of nonlinear load. In voltage source type nonlinear load the THD is compensated from 23.24% to 3.19 by using P-I controller which is represented in Table 2.

In current source type nonlinear load the THD is compensated from 11.27% to 4.64% which is represented in Table-3. Hence in both the case the after compensation the supply current is reduced to less than 5%, the harmonic limit imposed by the IEEE-519 & IEC-6000-3 standard.

6.2 SCOPE OF FUTURE WORK

Experimental investigations can be done on shunt hybrid power filter by developing a prototype model in the laboratory to verify the simulation results for both P-I and hysteresis controllers.

TABLE-4

Specification Parameters

Phase voltage and frequency	V_s=230v(rms), f_s=50Hz
Supply /line inductance	L_{sa}=L_{sb}=L_{sc}=2 mH
Rectifier front-end inductance	L_{la} =L_{lb}=L_{lc}=30 mH
For V-S Type Load resistance, load capacitance	R_L=20 Ω , C_L=500 μF
For C-S Type Load resistance, load inductance	R_L= 30 Ω , L_L=10 mH
Passive filter parameters	L_{pf}=14 mH, C_{pf}= 24 μF
Inverter dc- bus voltage and capacitance	V_{dc}=50v, C_{dc}=3000 μF
Controller Parameter	K_p=335.35, K_i=0.004

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