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IMPROVEMENT OF POWER QUALITY IN SHUNT ACTIVE POWER FILTERS USING DIFFERENT CONTROL TECHNIQUE WITH MODIFIED FUZZY BASED CONTROLLER

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ABSTRACT

Because many industrial and residential loads are nonlinear, low power distribution systems suffer from serious power quality problems. The primary cause of the overheating of the transformers in the distribution networks is the harmonics. One way to lessen the harmonics in the source current is to use specialized power devices, passive filters, and active filters. The modified shunt active power filter with the fuzzy logic controller was created to address the shortcomings of active power filters and traditional tuned filters. In this paper, three control methods—synchronous reference frame theory, real and reactive power theory, and indirect reference current theory—are used to investigate an efficient method of reducing the total harmonic distortion using a three-phase, three-wire shunt active filter. The fuzzy controller is used in conjunction with established control techniques to enhance the induction motor drive's performance. In order to outperform other control techniques in terms of decreased total harmonic distortion, DC link voltage, and enhanced speed performance of the induction motor drive, the hardware configuration for the suggested fuzzy-based control methodology was put into place. Hardware implementation allows for improved reactive power adjustment and further power factor correction.

1. INTRODUCTION

With a common DC link capacitor, linked inductor, and voltage (or) current source inverters, the Active Power Filter (APF) is constructed. Depending on the needs, this may be shunted or put in series with the distribution line.

The static compensator (STATCOM) and the shunt active power filter (SAPF) use the same architecture. In power transmission systems, the SAPF is utilized for voltage regulation, reactive power compensation, and power factor correction. Through the coupling inductor, SAPF is linked to the line in shunt. By injecting a compensating harmonic current equivalent in magnitude to the source current harmonics, SAPF compensates the load current harmonics. Similarly, to provide compensation against voltage-related Power Quality (PQ) issues, the Series APF (SSPF) is connected in series with a transformer. By adding a series compensating voltage to the supply voltage, SSPF corrects voltage imbalance, sag, and swell. In order to lower the APF's rating and cost in high power applications, hybrid power filters, or HPFs, were created. They feature a structure that either parallelly or in series joins SAPF and SSPF or Passive Power Filter (PPF).

The most popular ways to get distortion-free current, almost a perfect Power Factor (PF), and improved reactive power compensation are via the usage of APF and HPF. Nonetheless, this APF and HPF are insufficient to adequately correct for voltage-related PQ issues such sag and swell. 11 Interest in APF for harmonic distortion reduction has increased as power electronics have advanced. We talk about the different harmonic generating loads and the mitigation techniques that use PPF, APF, and HPF. The solution known as a line voltage regulator/conditioner (LVRC) makes use of both a parallel and a series APF. The output voltage is controlled by the series filter.

By producing the harmonic current needed by the loads connected to the output side, the parallel filter reflects a linear load back to the source. Using a voltage source power converter with a series-connected inductor and capacitor, a unique three-phase APF is suggested and put into practice. Through the use of series-connected inductor and capacitor combinations, the power converter is managed to provide a compensating voltage that is then transformed into a compensating current. To reduce the harmonic currents produced by nonlinear loads, the compensatory current flows into the power feeder. In addition to compensating for harmonics and reactive power for various unbalanced nonlinear loads, the three-phase, four-wire SAPF also suppresses the neutral current. One of the most important power quality problems that has generated a lot of study attention is the current harmonics. The SAPF is the greatest way to reduce harmonic contamination, but how fast and precisely its control algorithms can operate will determine how successful it is. This paper examines the several kinds of control algorithms that are now in use and have been used to regulate SAPF's functioning. Examined and discussed include synchronizer algorithms, harmonic extraction, voltage regulation of DC-link capacitors, current control, and current management. 12 To determine the advantages and disadvantages of each control algorithm, the most pertinent methods that have been used are outlined and compared in an orderly fashion. The inverter, along with the coupling inductor and DC link capacitor, is one of the main parts of the SAPF.

The filtering method consists of four steps: signal conditioning, reference signal extraction, firing pulse generation, and DC-link voltage regulation. By injecting the harmonic current, a filter linked in parallel between the source and load may efficiently lower the percentage of Total Harmonic Distortion (THD) in the source current. The coupling inductor connects the filter to the line. The filter circuit's DClink capacitor maintains a steady DC voltage with less ripple. The DC-link capacitor serves as a storage device to provide the power differential between the source and the load during transient situations. It is necessary to adjust the capacitor's voltage fluctuations in accordance with changes in the load. The line voltage is the primary factor that influences the capacitor value decision. The controllers are used to regulate the value of the capacitor.

Both the compound current control strategy, which comprises of a proportional-integral (PI) controller and a repetitive controller, and the selective harmonic detection approach, which is based on the Discrete Fourier Transformation (DFT) algorithm, are implemented. As a result, exceptional compensation performances are attained under both balanced and unbalanced loads. In this study, the voltage across the capacitor is controlled using a traditional PI controller. Additionally, in order to generate the firing pulses, the electrical parameters (V and I) at PCC must be sensed in order to track fluctuations in the load. Using a current transformer or hall effect sensor, the measured electrical characteristics are regarded as reference signals. It is retrieved using various control methods subsequent to the reference signals being sensed. 13 Here, the control techniques of the p-q theory, the Indirect Reference Current Theory (IRCT), and the Synchronous Reference Frame (SRF) theory are used. Hysteresis Current Control is utilized to provide the firing pulse for the inverter. Nevertheless, the induction motor's speed regulation presented a challenge since it was hard to achieve.

Fuzzy logic controller improvements quickly solved this issue. There is a discussion of the many proportional integral (PI) controller speed control techniques. This allows for the interspersion of a fuzzy-based

SRF controller, which eliminates the need for a separate PI controller. There is a chance that the fuzzy logic controller will use several kinds of speed-adjustable signals. Certain choices have a high degree of accuracy and are thus sensitive to changes in the parameters. Section II of this study discusses the design and implementation of the proposed system's shunt active power filter.

2. FACTS

The term Flexible AC Transmission Systems, or FACTS, has gained popularity recently as a technique of achieving more controllability in power systems via the use of power electronic equipment. Globally, a number of FACTS-devices have been released for diverse uses. A variety of novel gadget types are now being implemented in real-world settings. Controllability is utilized in the majority of applications to prevent expensive or physically demanding expansions of power systems, such as upgrades or new substations and power lines. FACTS-devices increase the use of already-existing installations and enable greater response to changing operating circumstances. The fundamental uses of FACTS devices include: power flow control; voltage control; reactive power compensation; stability enhancement; power quality enhancement; power conditioning 15; flicker mitigation; and interconnection of distributed and renewable energy sources and storages.

Series compensation, phase shift control, or switched or controlled shunt compensation are the methods used by FACTS-devices to exert their impact. The gadgets function electrically as quick controllers of voltage, current, or impedance. Reaction times may be as quick as less than a second thanks to the power electronic.

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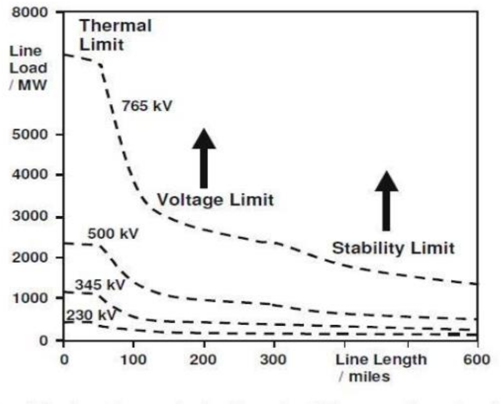


2.2 Configurations of FACTS-Devices:

2.2.1 Shunt Devices:

The SVC, or the variant with the Voltage Source Converter known as STATCOM, is the most often used FACTS device. These shunt devices are compensators for reactive power. Transmission, distribution, and industrial networks primarily use these applications for:

- Reducing undesired reactive power flows, which lowers network losses.
- Maintaining balanced reactive power exchanges in contractual agreements.
- Consumer compensation and improved power quality, particularly in instances of extreme demand fluctuations, such as in the case of industrial machinery, metal melting facilities, railways, or subterranean train systems.
- Thyristor converter compensation, such as in traditional HVDC lines.
- Static or transient stability is improved.

2.3 SVC: Reactive power is produced and consumed by electrical loads. Reactive power balance in a grid fluctuates because the transmitted load changes significantly hourly. Unacceptable voltage amplitude changes, a voltage depression, or, in the worst case scenario, a voltage collapse, may be the outcome.

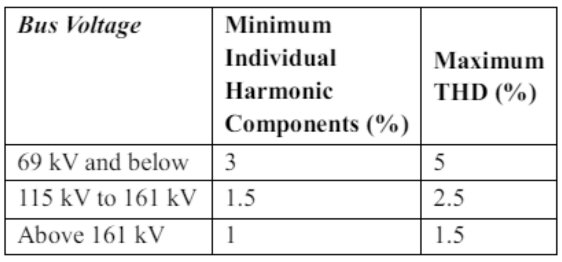
3. GENERAL THEORY OF ACTIVE POWER FILTERS

3.1 Introduction

Adjustable speed drives (ASDs), bulk rectifiers, furnaces, computer supplies, and other nonlinear loads draw non-sinusoidal currents with harmonics from the supply, which results in voltage harmonics. Increased power system losses, excessive heating in spinning equipment, interference with adjacent control and communication circuits, and other issues are all brought on by harmonic currents.

Table 1.1

IEEE 519 Voltage Limits



Bus Voltage	Minimum Individual Harmonic Components (%)	Maximum THD (%)
69 kV and below	3	5
115 kV to 161 kV	1.5	2.5
Above 161 kV	1	1.5

3.2 Classifications of Active Power Filters

3.2.1 Converter based classification Current Source Inverter (CSI)

Voltage Source Inverter (Fig. 4.1) with Active Power Filter Within this category, there are two classifications: Active Power Filter (VSI) (Fig. 4.2). In order to provide the harmonic current needed by the nonlinear loads, the current source inverter acts as a non-sinusoidal current source. Reverse voltage blocking is achieved by connecting a diode in series with the self-commutating device (IGBT). Nevertheless, GTO-based systems have limited switching frequencies but do not need a series diode. Although they have greater losses and need larger quantities of parallel ac power capacitors, they are thought to be adequately dependable. Additionally, they cannot be utilized to raise performance in multistep or multilayer modes.

4 .PROPOSED SHUNT ACTIVE FILTER WITH CONTROLLERS

4.1 DESIGN AND IMPLEMENTATION OF SHUNT ACTIVE POWER FILTER

A three-phase three-wire SAPF is considered. While designing the filter parameters, the switches in the inverter are considered ideal switches. The filter inductors are taken as pure inductances. Load currents are assumed to be balanced. SAPF ratings are calculated from the formulae given in equations (1) to (7). The RMS value of the rectifier is calculated using equation (1),

Irms = 0.816Io

where Io is the rectifier output current Fundamental components of rectifier input current is represented as

I1 = 0.779Io

The harmonic current (Iph) is found by

$$I_h = \sqrt{(I_{rms}^2 - I_1^2)}$$

The rating (S) of the SAPF is calculated as

S = 3Iph ∗ phase voltage

Voltage across DC link capacitor is mentioned as

$$\mathrm{V_{DCvoltage}} = \frac{2\sqrt{2}V_{LL}}{\sqrt{3}m},$$

where VLL- AC line output voltage and m - modulation index DC link capacitor,

$$\mathrm{C_{DC}} = \frac{I_{sapf}}{2\omega V_{DCripple}},$$

where Isapf is the active filter supply current, VDC ripple is the maximum DC link ripple voltage (1 to 3 % of VDCvoltage), ω = 2πf.

$$\text{Filter inductor, } \mathrm{L_C} = af\frac{\sqrt{3}\,V_{DCvoltage}}{12af_{sw}I_{ripple}},$$

where, ‘a’ is the overload factor.

4.2 CONTROL ALGORITHM OF SHUNT APF

The reference current to control shunt APF is extracted using three different techniques such as, SRF Theory, p-q theory and IRCT Method. Figure 1 depicts the schematic representation of the SRF control technique. Here, the feedback signals are the load side currents, PCC voltages, and DC-link capacitor voltage. Using Park’s transformation, the load currents in the a-b-c frame are transformed into a d-q-o frame. The currents iLd, iLq, and iLo are processed using the matrix equation (8).

$$\begin{bmatrix} i_{Ld}\\ i_{Lq}\\ i_{Lo}\end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2}\\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & \frac{1}{2}\\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & \frac{1}{2}\end{bmatrix}\begin{bmatrix} i_{La}\\ i_{Lb}\\ i_{Lc}\end{bmatrix}$$

Equations (9) and (10) represent the AC and DC components present in the d-q currents. The current signals are synchronized with the PCC voltages by connecting the three-phased Phase Locked Loop (PLL). The d-q current components are passed through a first-order Butter worth low Pass Filter (BPF) for obtaining the fundamental quantities of iLd and iLq.

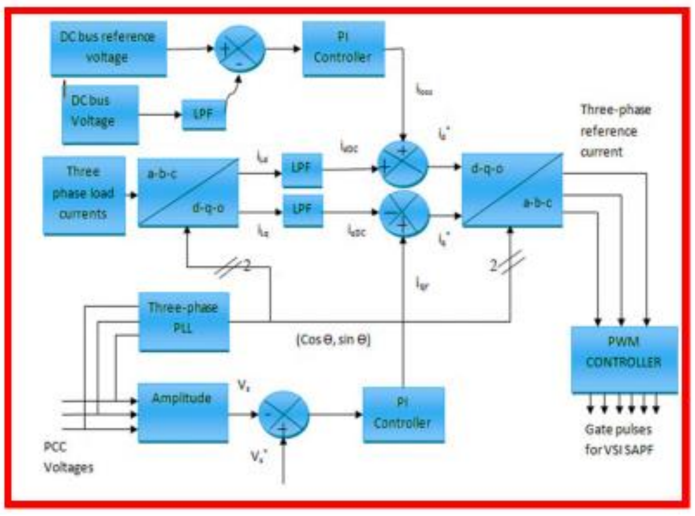


FIGURE 4.1. Schematic representation of the SRF control technique for Shunt APF.

iLq. iLd = idDC + idAC

iLq = iqDC + iqAC

The DC quantities extracted by the Low Pass Filter (LPF) are considered as fundamental quantities, they are separated from the harmonic signals. For the compensation of harmonics, the D axis components are mainly taken into consideration. The error signal to the conventional PI controller is the variations amongst the reference and the DC bus voltage to maintain the DC capacitor voltage of the inverter. Hence, the required reference currents for shunt APF are generated from the PI controller. The desired reference current is calculated from id-iq rotating frame using inverse transformation. Then, the gate pulses are generated using a hysteresis current controller. The required reference current calculated from id-iq rotating frame using inverse transformation is,

$$\begin{bmatrix} i_{sa}\\ i_{Lq}\\ i_{Lo}\end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\theta & -\sin\theta & \frac{1}{2}\\ \cos\left(\theta-\frac{2\pi}{3}\right) & -\sin\left(\theta-\frac{2\pi}{3}\right) & \frac{1}{2}\\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & \frac{1}{2}\end{bmatrix}$$

The second control method shown in Figure 2 is the instantaneous reactive power theory control algorithm, in which the real and reactive power is obtained using Clark’s transformation. The three-phase PCC voltages and the load currents are taken as a feedback signal to calculate the real and reactive power in the instantaneous reactive power theory algorithm. There are four main steps to be followed to find the reference current. In the first step, the threephase voltages and currents are changed as two-phase α-β quantities (vα, vβ and iα, iβ) with the help of the following

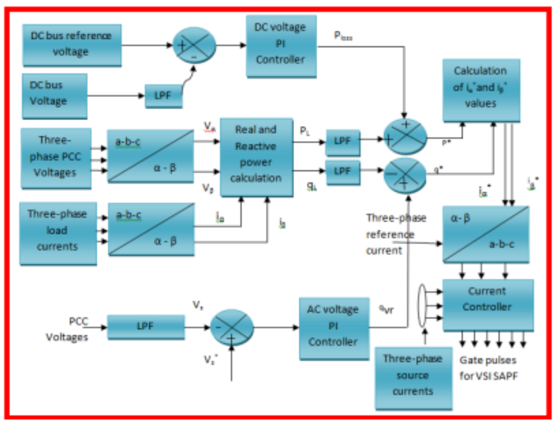


FIGURE 4.2. Schematic layout of the p-q theory control technique for SAPF.

equations (12) and (13)

$$\begin{pmatrix} v_\alpha \\ v_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix}$$

$$\begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{pmatrix}$$

In the second step, the required real and reactive power is obtained from the relations given in equation (14).

$$\begin{pmatrix} P_L \\ Q_L \end{pmatrix} = \begin{pmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{pmatrix} \begin{pmatrix} i_\alpha \\ i_\beta \end{pmatrix}$$

In the third step, the AC component of active (P∗) and reactive (q∗) power are separated from the DC component by considering the LPF as shown in Figure 2. Here, the fundamental components of the load power are considered as DC components (p− _Landq−_L), and harmonic components are considered as AC components (p∼_Landq∼_L) which are expressed in the equations (15) and (16).

pL = ¯pL + ˜pL

qL = ¯qL + ˜qL

In step four, the reference currents are calculated by the use of inverse Clark's transformation. The currents isa∗ , isb∗ , and isc∗ were obtained by the equation (17).

$$\begin{pmatrix} i^*_{sa} \\ i^*_{sb} \\ i^*_{sc} \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{pmatrix}^{-1} \begin{pmatrix} p* \\ q* \end{pmatrix}$$

The third control strategy given in Figure 3 is the unit template-based control algorithm where the indirect method of current controlling has been introduced for obtaining the reference current. The voltage at PCC is sensed for estimating the amplitude of supply current from the three-phase. In this method, the amplitude of the voltage is obtained using the formula in equation (18).

Estimated voltage = {2/3(vsa2 + vsb2 + vsc2)}1/2

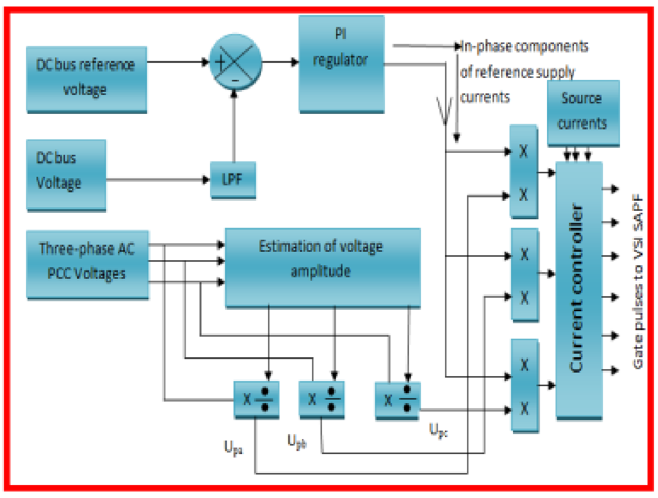


FIGURE 4.3. Schematic layout of indirect method of current control for SAPF.

4.1 DESIGN AND IMPLEMENTATION OF SHUNT ACTIVE POWER FILTER

One option is a three-wire, three-phase SAPF. The inverter switches are appropriate switches to use when determining the filter settings. It is assumed that the filter inductors are pure inductances. It is believed that load currents are balanced. Equations (1) through (7) provide the formulas used to determine SAPF ratings. Equation (1) may be used to compute the rectifier's RMS value: Irms = 0.816Io, where Io is the rectifier output current. The formula for the fundamental components of rectifier input current is I1 = 0.779Io. One may determine the harmonic current (Iph) via

$$I_h = \sqrt{(I_{rms}^2 - I_1^2)}$$

4.2 CONTROL ALGORITHM OF SHUNT APF

Three methods are used to extract the reference current to regulate shunt APF: p-q theory, IRCT method, and SRF theory. The SRF control technique's schematic depiction is shown in Figure 1. The load side currents, PCC voltages, and DC-link capacitor voltage are the feedback signals in this case. The load currents in the a-b-c frame are changed into a d-q-o frame using Park's transformation. The matrix equation (8) is used to process the currents iLd, iLq, and iLo.

$$\begin{bmatrix} i_{Ld} \\ i_{Lq} \\ i_{Lo} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} cos\theta & -sin\theta & \frac{1}{2} \\ cos\left(\theta - \frac{2\pi}{3}\right) & -sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{2} \\ cos\left(\theta + \frac{2\pi}{3}\right) & sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_{La} \\ i_{Lb} \\ i_{Lc} \end{bmatrix}$$

5 .OUTPUT SCREENS

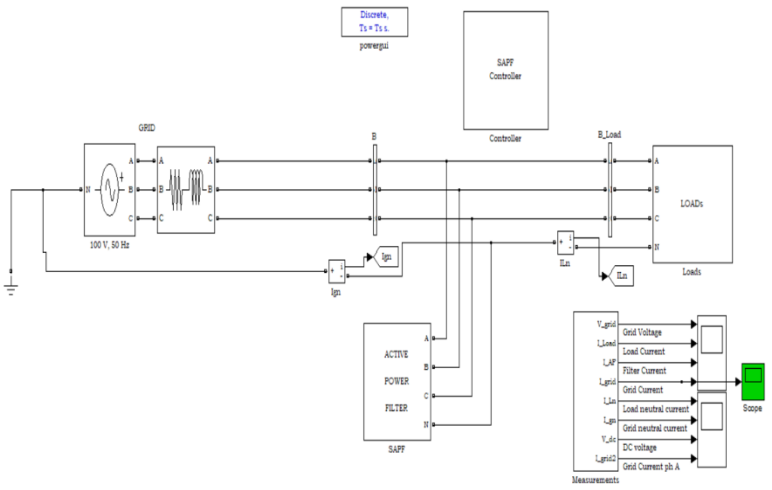


Fig 5.1 simulink model of SAPF

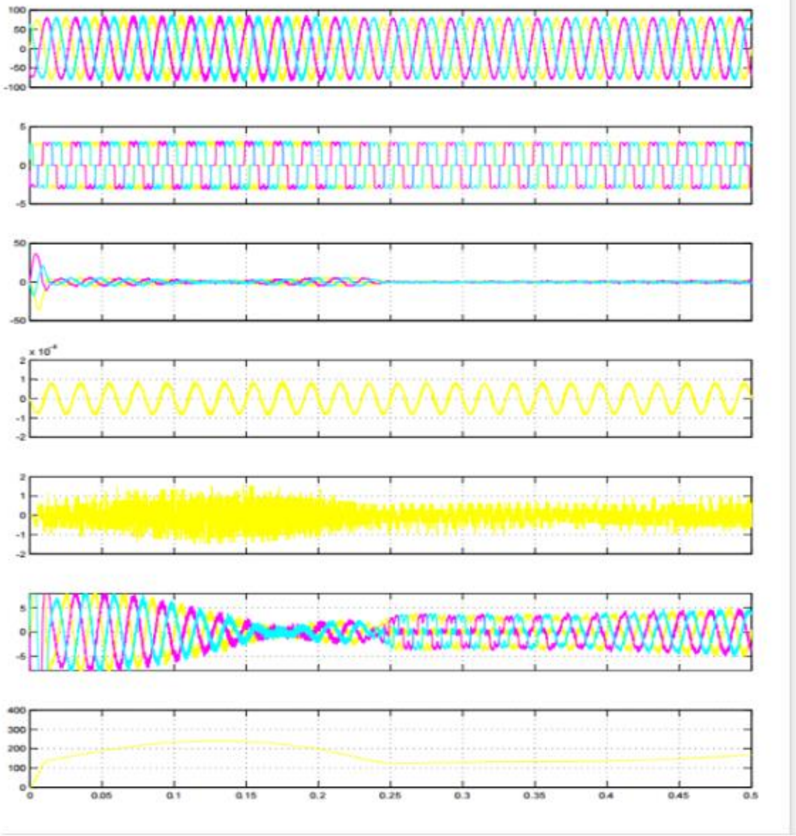


Fig 5.1 Performance Of Sapf

6 CONCLUSION

Analysis has been done on the non-linear bridge rectifier system simulation both with and without SAPF.The percentage of total harmonic distortion (THD) has been reduced from 63.8% to 0.48 % using the SRF technique, 2.04% using the p-q method, 6.67 % using the IRCT method, 1.30 % for the induction motor driving load, and 1.07 % when considering various loads. The hardware configuration used for the suggested work improves power factor by 6.38%, reactive power compensation reaches 88.3%, and source current harmonics are decreased from 23.9% to 3.2%.We have examined the system under two different load scenarios. The overall harmonic distortion for the bridge rectifier load was lowered to 0.48 percent. The percentage THD in the induction motor drive load is 1.30%, indicating that the active filter is reducing the percentage THD for various kinds of loads and that fuzzy-based SAPF approaches have been used to produce robust speed performance.

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