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Comparative Analysis of Harmonics with and Without Shunt Active Power Filter

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Abstract: **Electricity consumption had been increased so rapidly once in line with the development of the country to achieve its status as the industrial countries. The large consumption of electrical energy, one thing that plays an important role in a distribution system is the quality of electrical power itself. The distribution system will have many problems related to efficiency and functionality of electrical equipment. Therefore, the entire system does not operate efficiently due to the presence of harmonic in the distribution system. Among of them, one of the disorders that cause poor power quality is harmonic. This disturbance causes electrical equipment used to heat and cannot function properly. Thereby, the aim of this paper is to design and develop of a three phase shunt active power filter for harmonics reduction in industrial using MATLAB/SIMULINK[1,2].**

Keywords: **Power System, Harmonic Distortion, Shunt Active Power Filter, Non-Linear Loads, Total Harmonic Distortion.**

1. INTRODUCTION

Power quality is important in the distribution system. To provide power supply with good quality is not easy because it depends on the type of load used. Phenomenon that causes an interruption in the electrical system such as overvoltage, voltage sags, voltage surges and harmonic [3]. Harmonic distortion problem has existed in the power system for a long time. it causes a wave of the line current and voltage in the power system to be distorted. In the past, discussions about the existence of harmonics have been discussed. However, at that time, the impact and influence of harmonic distortion is slightly lower than at present, where it only covers in the delta grounded w-ye connection of the transformer and also in some design of power transformer [4]. At present, the creation of modern equipment, especially electronic equipment and also the increased use of non-linear loads in industry has produced harmonic distortion, harmonic distortion in electrical systems became more serious because the use of electronic equipment are among the largest contributors to the formation of harmonic distortion. In recent years, with the increasing use of adjustable speed drives, arc furnace, controlled and uncontrolled rectifiers and other nonlinear loads, the power distribution system is polluted with harmonics. Such harmonics not only create more voltage and current stress but also are responsible for Electromagnetic interference, more losses, capacitor failure due to overloading, harmonic resonance, etc. Introduction of strict legislation such as IEEE519 [5] limits the maximum amount of harmonics (THD-Total Harmonic Distortion) that a supply system can tolerate for a particular type of load. Therefore, use of active or passive type filters is essential. To solve the current harmonic related problems, passive filters connected in several circuit configurations present a low cost solution. However passive filter implementations to filter out the current harmonics have the following disadvantages:

- Possibility of resonances with the source Impedance
- Supply impedance dependent system performance
- Fixed compensation

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In order to diminish the preceding disadvantages of the passive filters, active power filters(APF) have been worked on and developed in recent years. Elimination of the current harmonics, reactive power compensation and voltage regulation are the main functions of active filters for the improvement of power quality. APFs have a number of advantages over the passive filters. First of all, they can suppress not only the supply current harmonics, but also the reactive currents. Moreover, unlike passive filters, they do not cause harmful resonances with the power distribution systems. Consequently, the APF performances are independent of the power distribution system properties .On the other hand, APFs have some drawbacks.APF necessitates fast switching of high currents in the power circuit resulting high frequency noise that may cause an electromagnetic interference (EMI) in the power distribution system.

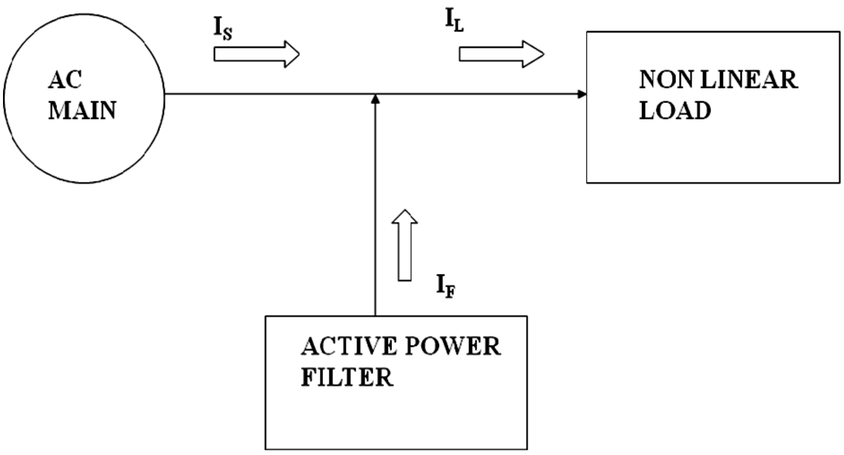

Fig.1 Active power filter with non-linear load.

2. INSTANTANEOUS ACTIVE AND REACTIVE POWER THEORY

This method offers a good precision and ease of implementation. Its main disadvantage is that it can't be applied in the case of unbalanced grid voltage [13]. In this case, A Self Tuning Filter (STF) can be used after the measurement of the grid voltages to extract the fundamental balanced three phase voltage components of the distorted unbalanced one. This transformation may be viewed as a projection of the three-phase quantities onto a stationary two-axis reference frame. The Clarke transformation for the voltage variables is given by [14]:

$$\begin{bmatrix} u_\alpha \\ u_\beta \\ u_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} u_a \\ u_b \\ u_c \end{bmatrix} \qquad \text{...... .... (1)}$$

Similarly, this transform can be applied on the distorted load currents to give

$$\begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \\ i_{l0} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_{la} \\ i_{lb} \\ i_{lc} \end{bmatrix} \qquad \text{..................(2)}$$

The instantaneous active power *p(t)* can be defined by:

$$p(t) = u_a\, i_{la} + u_b\, i_{lb} + u_c\, i_{lc} \qquad \text{............... ... (3)}$$

This expression is given in the stationary frame by:

$$p(t) = u_\alpha\, i_{l\alpha} + u_\beta\, i_{l\beta}$$

$$p_0(t) = u_0\, i_{l0} \qquad \text{..................(4)}$$

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Where, *p(t)* is the instantaneous active power, $p_0(t)$ is the instantaneous homo-polar sequence power. Similarly the instantaneous reactive power can be given by:

$$q(t) = -\frac{1}{\sqrt{3}}[(u_a - u_b)i_{lc} + (u_b - u_c)i_{la} + (u_c - u_a)i_{lb} = u_\alpha\, i_{l\beta} + u_\beta\, i_{l\alpha} \qquad \ldots\ldots(5)$$

From eqns. 4 and 5, the instantaneous active and reactive power can be given in matrix form by:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} u_\alpha & u_\beta \\ u_\beta & u_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

In order to separate the harmonics from the fundamental of the load currents, it is sufficient to separate the alternating term of the instantaneous power from the direct.After the separation of the direct and alternating terms of instantaneous power, the harmonic components of the load currents can be given using the inverse of equation (3.6) which gives:

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p}_l \\ \tilde{q}_l \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(7)$$

The inverse Clarke transform can be used as follow:

$$\begin{bmatrix} i_{fa}^* \\ i_{fb}^* \\ i_{fc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

Figure presents the principle of the active and reactive instantaneous power.

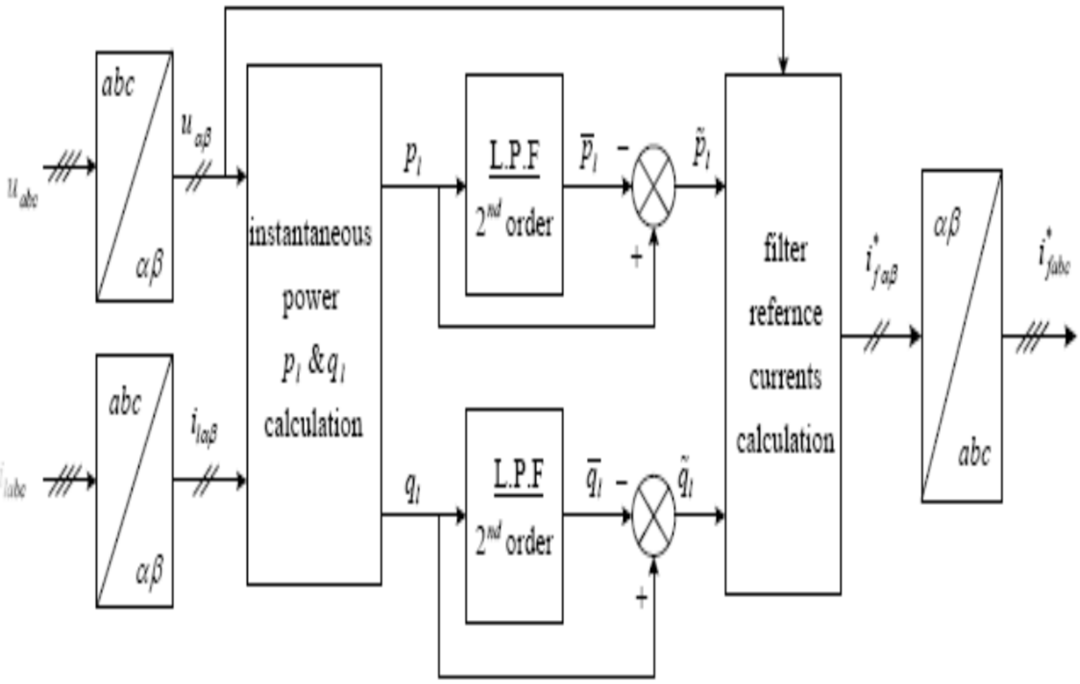

Fig.3 Principle of instantaneous active and reactive power theory

3. MODELLING OF SHUNT ACTIVE POWER FILTER

The simulation model of system without SAPF is shown in fig 4.1 and the simulation model of system with SAPF is shown in fig 3 which shunt active power filter (SAPF) is connected across the non linear load. The control of Shunt active power filter (SAPF) is divided in two parts. First part is used for the harmonic current extraction. There are instantaneous active and reactive power method (p-q method). Second part is used for the generation of gate pulse to control of voltage source inverter. Hysteresis Current Control Method is used.

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3.1 Simulation Model of System without SAPF:

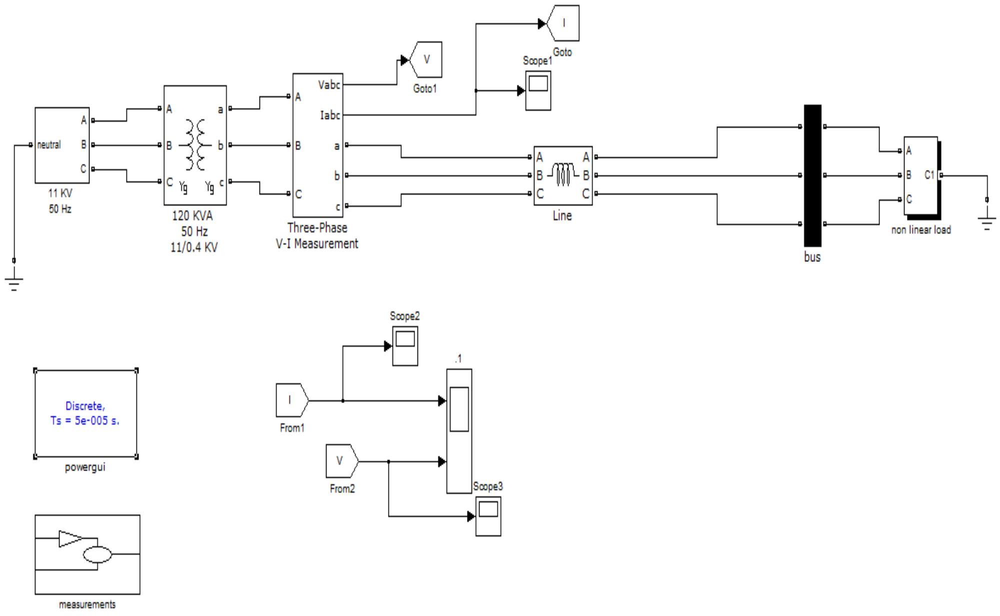

Fig.4. Simulation model of system without SAPF

3.1.1 Simulation Result:

shows source current without shunt active filter. Due to the presence of the non linear load, so the current waveform is in distorted manner. The current is taken along the Y-axis and time is taken along the X-axis..

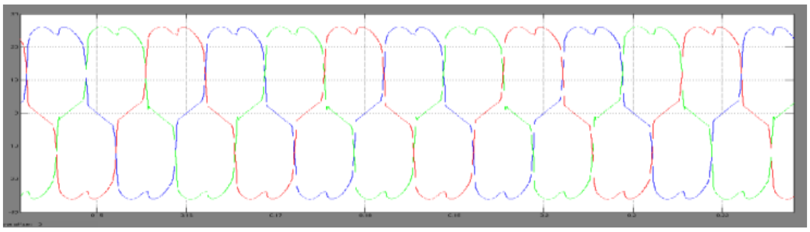

Fig.5 Voltage and current waveform without filter

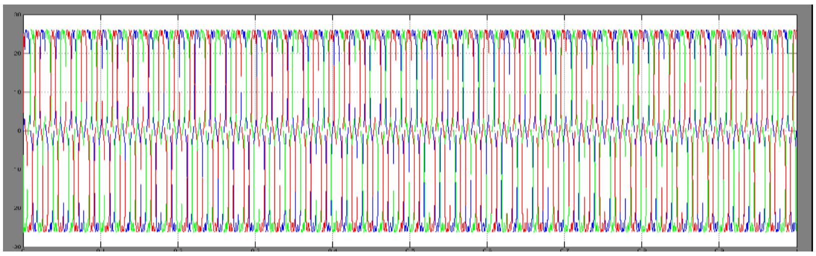

Fig.6 voltage and current waveform without filter

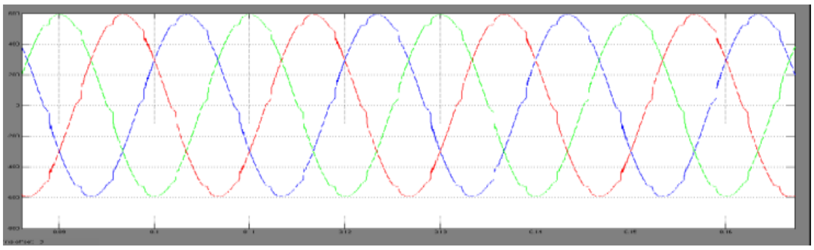

Fig 7.Voltage and Current Waveform without Filter

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3.2 Simulation Model of System with Shunt Active Power Filter:

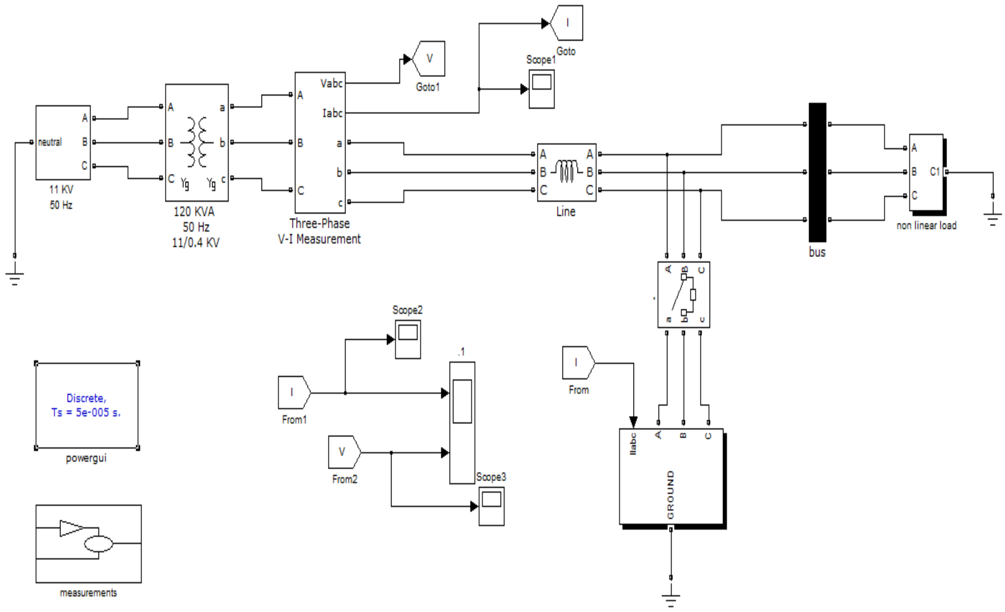

Fig.8 Simulation model of system with SAPF

3.2.1 Simulation Results:

A number of simulations have been performed to check the working of the shunt active power filter under various non-linear loadings (w.r.t connection of the loads at the PCC) and nonideal supply. The analysis of the results show that the working of the active filter is very satisfied to compensate the harmonics and reactive power even under unbalanced and distorted conditions of distribution supply.

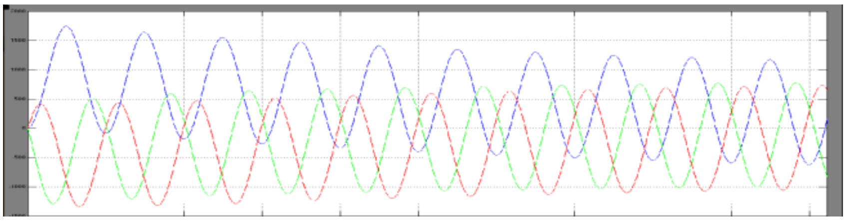

Fig.9 Voltage and current waveform with SAPF

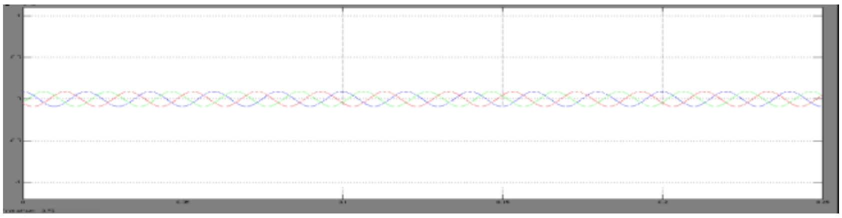

Fig.10 Voltage and current waveform with SAPF

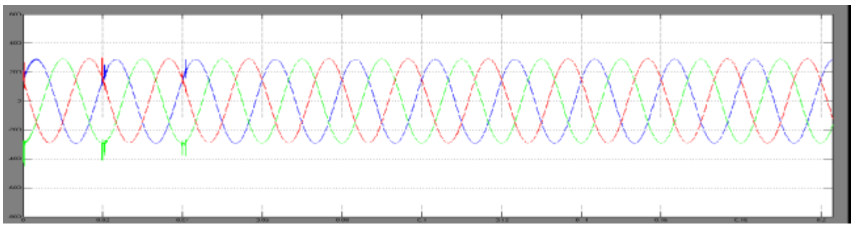

Fig.11 Voltage and current waveform with SAPF

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4. FFT ANALYSIS

The following figure shows the THD analysis of source current without SAF. THD is found to be 20.49% respectively due to nonlinear load which creates harmonics in the three phase system. In order to reduce the THD the proposed system is implemented.

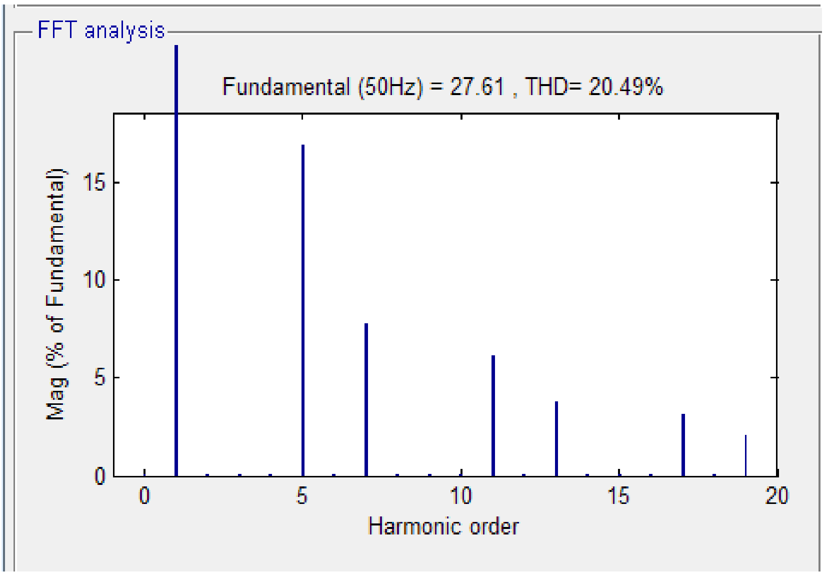

Figure FFT analysis without SAPF

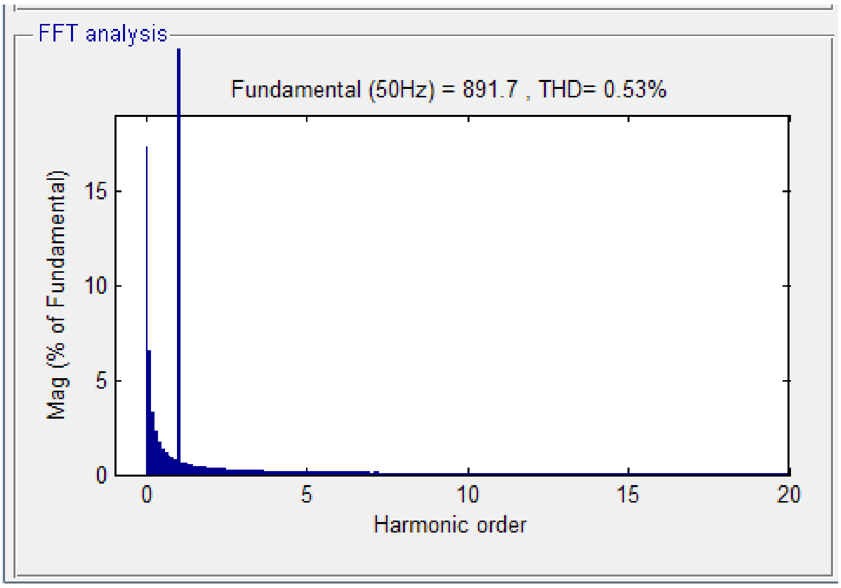

Figure FFT analysis with SAPF

Table.1 Comparison of THD in Source Current

THD IN SOURCE CURRENT BEFORE SHUNT ACTIVE FILTER	THD IN SOURCE CURRENT AFTER SHUNT ACTIVE FILTER
20.49%	0.53%

5. CONCLUSION

The three phase three wire shunt active filter with controller based on instantaneous active and reactive power (p-q) theory is simulated in MATLAB/SIMULINK to compensate the problems of the harmonics and reactive power which are encountered from power electronic non-linear loads. The performance of the shunt active power filter is investigated under different scenarios. It is investigated that the p-q theory based active filter manages to compensate the harmonics and reactive power of the power distribution network even under unbalanced and distorted supply voltages. The active power filter is able to reduce the THD in source current at a level well below the defined standards specified by power quality standards. The THD in source current after the active filtering is not exactly zero. It is because internal switching of the compensator itself generates some harmonics. In each of the case studied, the source current after the working of the active filter becomes perfectly sinusoidal, free from harmonics and in-phase with voltage of the main supply maintaining the unity power factor. In each simulation studied, multiple non-linear loads have been used to investigate the time response of the active filter. In each case it has noted that filter is successfully able to follow the reference currents with one power cycle with change in loads. It has been noted that if voltage unbalance or distortion or both are present in the system, the simple p-q theory didn't work well. It give rise the demand of the fundamental positive sequence voltage detector to extract the fundamental positive voltage form the unbalanced or distorted voltage. Once the fundamental positive sequence voltage is extracted, the theory worked very well. Even though the p-q theory has managed to compensate the harmonics and reactive power of the system and to produce the sinusoidal source current with unity power factor and free from harmonics.

6. FUTURE WORK

The scope of the future work can be to look for the solution of the following points:

- This work is based on three phase three wire system and the active filter does not work well if there is a zero sequence in the supply voltage. In future, a detailed analysis can be carried out for a 3 phase four wire filter in order to compensate the zero sequence present in the system.

- The work done in this thesis can be verified in the laboratory and further experimental study can be done to implement the APF for the compensation of harmonics and zero sequence.

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