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Simulation of PI and Fuzzy Controlled Active Power Filter for Power Quality Improvement

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Abstract-This project presents the optimization of shunt active power filter parameters based on fuzzy logic control. The current active filter control is based on constant, fuzzy hysteresis band techniques, which are employed to derive the switching signals and also to choose the optimal value of the decoupling inductance. The DC voltage controller optimizes the energy storage of the DC capacitor, where proportional integral and fuzzy logic controllers are employed. . In a power system harmonics caused by highly nonlinear devices degrade its performance. Thus harmonics is important to analyze and criticize the various harmonic problems in power system and acquaint the appropriate solution technique. Now day modern power systems are continuously being expand and upgraded to cater they require of ever growing power demand. Active power filter continues to attract considerable attention. Because of sensitivity of consumers on power quality and advancement in power electronics. Active power filter technology is the most efficient way to compensate reactive power and cancel out low order harmonics generated by nonlinear loads. An active power filter is a device that is connected in parallel to and cancels the reactive and harmonic currents from the group of nonlinear loads so that the resulting total current drawn from the ac main is sinusoidal. The shunt active power filter was considered to be the most basic configuration for the APF. The simulations are obtained by MATLAB/SIMULINK.

Keywords— nonlinear loads; harmonic pollution; shunt active power filter; compensation; total harmonic distortion

I.INTRODUCTION

In a modern power system, increasing of loads and nonlinear equipment's have been demanding the compensation of the disturbances caused for them. These non-linear loads may cause poor power factor and high degree of harmonics. Active power filter (APF) can solve problems of harmonic and reactive power simultaneously. APF's consisting of voltage source inverters and a dc capacitor have been researched and developed for improving the power factor and stability of transmission systems. APF have the ability to adjust the amplitude of the synthesized ac voltage of the inverters by means of pulse width modulation or by control of the dc-link voltage, thus drawing either leading or lagging reactive power from the supply. APF's are an up-to-date solution to power quality problems. Shunt APF's allowed the compensation of current harmonics and unbalance, together with power factor correction, and can be a much better solution than conventional approach (capacitors and passive filters). The simplest method of eliminating line current harmonics and improving the system power factor is to use passive LC filters. However, bulk passive components, series and parallel resonance and a fixed compensation characteristic are the main drawbacks of passive LC filters.

Harmonic compensations have become increasingly important in power systems due to the widespread use of adjustable-speed drives, arc furnace, switched-mode power Supply, uninterruptible power supply, etc. Harmonics not only Increase the losses but also produce unwanted disturbance to the communication network, more voltage and/or current Stress, etc. Different mitigation solutions, e.g., passive filter, Active power line conditioner, and also hybrid filter, have been Proposed and used. Recent technological advancement of switching devices and availability of cheaper controlling devices, E.g., DSP-field-programmable-gate-array-based system, Make active power line conditioner a natural choice to compensate for harmonics. Shunt-type active power filter (APF) is used to eliminate the current harmonics. The dynamic performance of an APF is mainly dependent on how quickly and how accurately the harmonic components are extracted from the load current. Many harmonic extraction Techniques are available, and their responses have been explored. In this project a new concept is proposed that is FBD algorithm in three-phase four-wire shunt active power filter to compensate the harmonics.

In APF design and control, instantaneous reactive power theory was often served as the basis for the calculation of compensation current. In this theory, the mains voltage was assumed to be an ideal source in the calculation process. However, in most of time and most of industry power systems, mains voltage may be unbalanced and/or distorted. Under such scenarios, this theory may not be valid for application. The *p–q* theory, since its proposal, has been applied in the control of three-phase active power filters. However, power system voltages being often non-ideal, in distorted voltage systems the control using the *p–q* theory does not provide good performance. For improving APF performance under non-ideal mains voltages, new control methods are proposed by Komatsu and Kawabata and Huang and Chen and Hsu. This paper presents performance improvement of the shunt active power filter (SAPF), composed of the voltage inverter bridges having six IGBTs switches, DC-bus capacitor voltage source, and passive filter (Lf, R f) connected to

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the line supply voltage source fed nonlinear load. The non-linear load is a three-phase full-bridge diode rectifier supplying a RL load, shown as fig. 1

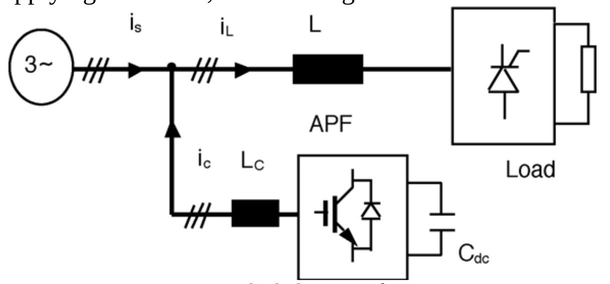

Fig: 1 Block diagram of APF

II .INSTANTANEOUS POWER THEORY

Many methods to recognize and extract the harmonic voltage and current distortions which are classified as frequency analysis, time domain analysis and time frequency approach [9]. Instantaneous active and reactive power theory, (p–q theory) in time domain, can be used to identify the reference harmonic currents [9, 10]. Offers the advantage to choosing the disturbance harmonics with precision speed and ease implementation [10, 11]. The first step of this method to transforming the three phase (a, b, c) voltages and currents to two-phase (α, β) using the direct conversion of Concordia. The principle adjustment of this method is to extract the fundamental component and harmonic removed component using low pass filters (LPF) [10, 12 and 13]. The voltages and currents at the points of connections absorptive by nonlinear load can be converted by the components of Concordia into:

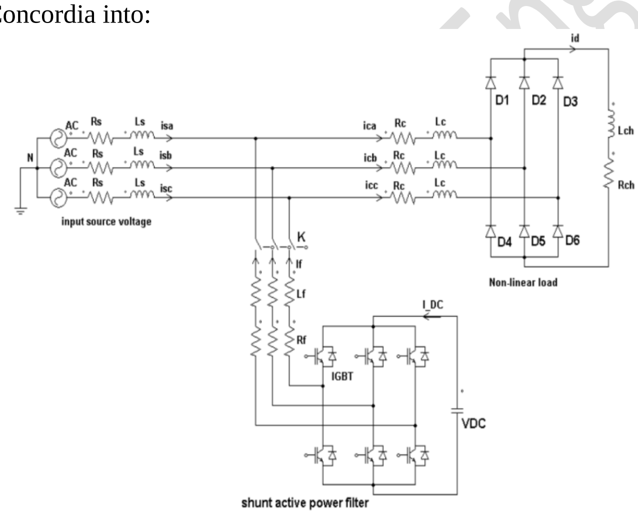

Fig.2. Simplified proposed of shunt active power filter

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix} \tag{1}$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & \frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} i_{Sa} \\ i_{Sb} \\ i_{Sc} \end{bmatrix} \tag{2}$$

The instantaneous real and imaginary power can be expressed by the following system:

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

The instantaneous real and imaginary power can be decomposed into two AC and DC parts. The DC part resulted from the fundamental current and voltage and the AC part resulted from the harmonics [10, 14]:

$$p = \overline{p} + \widetilde{p} \tag{4}$$

$$q = \overline{q} + \widetilde{q} \tag{5}$$

DC average value of the instantaneous real and imaginary power respectively, It's corresponds to the resulted from the fundamental current and voltage from the power source to the load.

AC value of the instantaneous real and imaginary power respectively, it does not have average value, and is related to the harmonic currents and voltage from the power source to the load. The references currents are calculated by the following expression:

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} p \\ q \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \overline{p} \\ 0 \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} 0 \\ \overline{q} \end{bmatrix} + \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \widetilde{p} \\ \widetilde{q} \end{bmatrix} \tag{7}$$

$$\text{Here,} \quad \Delta = v_\alpha^2 + v_\beta^2 \tag{8}$$

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The reference current results based on the instantaneous real and imaginary power should be determined according to the flowing equation:

$$\begin{bmatrix} \tilde{i}_\alpha \\ \tilde{i}_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \cdot \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \tag{9}$$

Finally, we can calculate the reference harmonic current as:

$$\begin{bmatrix} i_{refa} \\ i_{refb} \\ i_{refc} \end{bmatrix} = \sqrt{\frac{2}{3}} \cdot \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \cdot \begin{bmatrix} \tilde{i}_\alpha \\ \tilde{i}_\beta \end{bmatrix} \tag{10}$$

III.HYSTERESIS BAND CURRENT TECHNIQUE

Hysteresis band current control does not need any information about the system parameters but has the disadvantage of uncontrolled switching frequency. The instantaneous value of the error can be calculated by subtracting from the identify reference harmonic currents (i_{ref}) obtained by using diagram bloc of (p–q theory), and the injection harmonic currents (i_{inj}) of (SAPF), subtraction between (i_{inj}) and (i_{ref}) , introduced in hysteresis band current to generate the gate pulses [9,15,16], The hysteresis control law is given as fig. 4

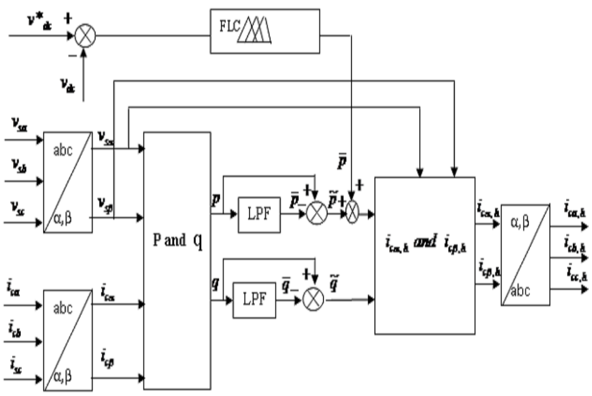

Fig.3 p– q Algorithm

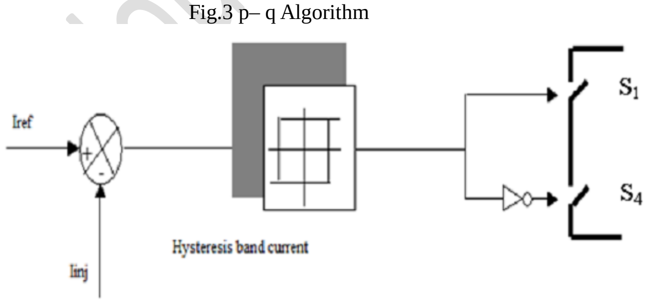

Fig.4 Hysteresis band current control

The output hysteresis band current control (S_{14}, S_{36}, S_{25}) are the gate pulses of six IGBTs switches:

$$S_{14} = \begin{cases} 0 & \text{if } S_1 \text{ is closed and } S_4 \text{ is open} \\ 1 & \text{if } S_4 \text{ is closed and } S_1 \text{ is open} \end{cases}$$

$$S_{36} = \begin{cases} 0 & \text{if } S_3 \text{ is closed and } S_6 \text{ is open} \\ 1 & \text{if } S_6 \text{ is closed and } S_3 \text{ is open} \end{cases} \tag{11}$$

$$S_{25} = \begin{cases} 0 & \text{if } S_2 \text{ is closed and } S_5 \text{ is open} \\ 1 & \text{if } S_5 \text{ is closed and } S_2 \text{ is open} \end{cases}$$

IV.CONTROL OF DCVOLTAGE SOURCE OF (SAPF)

The advantage control of DC bus capacitor voltage source of (SAPF) arises suitable transit of supply power necessary added to power active fluctuate. The storage capacity C absorbs the power fluctuations caused by the compensation of the reactive power [17, 18]. The normal conditioner, the real power supplied by the source should be equal to the real power demand of the load plus a small power to compensate the losses in the active filter [19]. Thus, the DC bus capacitor voltage can be kept at constant value and confirmed at a reference value. However, in the abnormal conditioner, In the presence of harmonics current, when the load changes, the real power balance between the source and the load will be disturbed. In this case, the real power poured most is compensated by the dc capacitor of inverter constructor of (SAPF). The changes of DC capacitor voltage from its reference most is regulate [19, 20]. A fuzzy logic controller is applied to maintain the constant voltage across the capacitor by minimizing the error between the capacitor voltage and its reference voltage, A fuzzy logic controller (FLC) converts is advanced control strategy, the based fuzzy rules are constructed by expert experience or knowledge database. In the input of (FLC) , the error e (k) and the Change of error •e (k) have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of (FLC) the fuzzy logic controller is presented by the control voltage µ (k) [21], the type of fuzzy inference engine used is Takagi-Sugeno. The linguistic input variables are defined as (N, Z, P,) which, negative, zero, and positive respectively. In The output the linguistic variables are defined as (PB, PM, PS) which, positive big, positive mean and, positive small zero respectively. The fuzzy rules are summarized in table I. The real power absorbed by DC voltage can be expressed by:

$$\bar{p} = \frac{d}{dt}\left(\frac{1}{2} c_{dc} \cdot v_{dc}{}^2\right) \tag{12}$$

For few variation value of DC voltage around its reference, we have:

$$\bar{p} = c_{dc} \cdot v^*{}_{dc} \cdot \frac{1}{2} \cdot \frac{d}{dt}(v_{dc}) \tag{13}$$

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After, the use of Laplace transforms:

$$v_{dc}(s) = \frac{2 \cdot \overline{p}(s)}{v^{*}_{dc} \cdot c_{dc} \cdot s} \tag{14}$$

The transfer function is defined:

$$G(s) = \frac{2}{v^{*}_{dc} \cdot c_{dc} \cdot s} \tag{15}$$

The instantaneous error e(k)between v_{dc} and its reference v^*_{dc} is given by :

$$e(k) = (v_{dc}(k)_{ref} - v^*_{dc}(k)) \cdot \alpha \tag{16}$$

The change of the error can be calculated by:

$$\Delta e(k) = (e(k) - e(k-1)) \cdot \beta \tag{17}$$

and β are the normalization coefficients [22]. The output of the fuzzy logic controller system is the change of the maximum current μ(K) , the Product block outputs P(K) is the result of multiplying of the error dc voltage and the output maximum current of FLC, obtained according to following equation:

$$P(k) = \mu(k) \cdot \Delta e(k) \tag{18}$$

The membership functions of the fuzzy logic controller are shown in fig. 5. The fuzzy inference mechanism used in this work is presented as following.

TABLE I. THE FUZZY RULES

$\Delta e(k)$ \ e(k)	N	Z	P
N	PB	PM	PB
Z	PB	PS	PB
P	PB	PM	PB

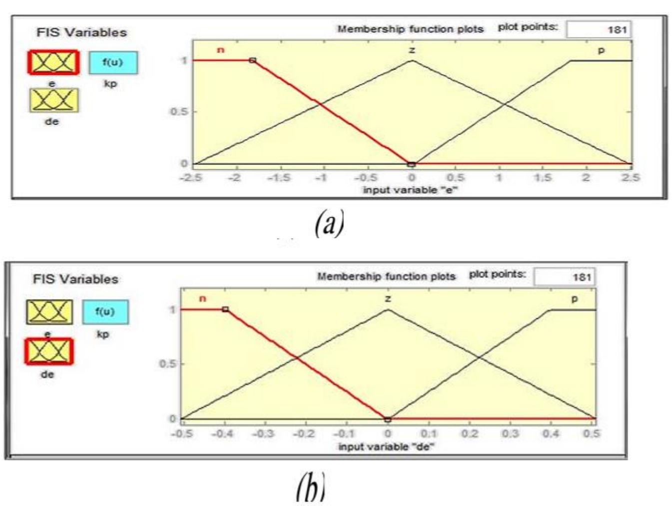

Fig.5. .Input member ship function

V. MATLAB/SIMULINK RESULTS

Here the simulation is carried by three different cases 1) Fuzzy controlled based APF in nonlinear load condition 2) Fuzzy controlled based without APF in nonlinear load condition 3) PI controlled based APF in nonlinear load condition

Case-1 Fuzzy controlled based APF in nonlinear load condition

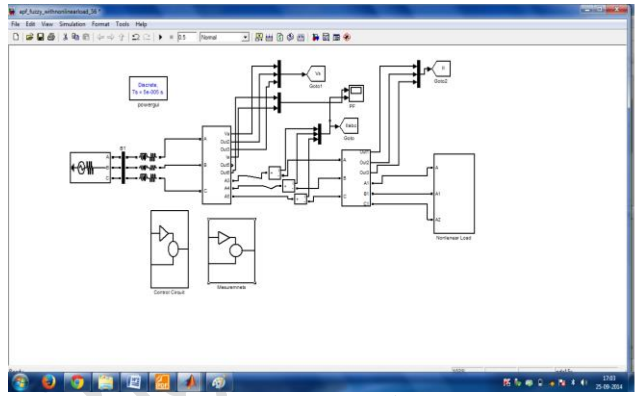

Fig.6 shows the Matlab/Simulink model of proposed converter with fuzzy controller without APF

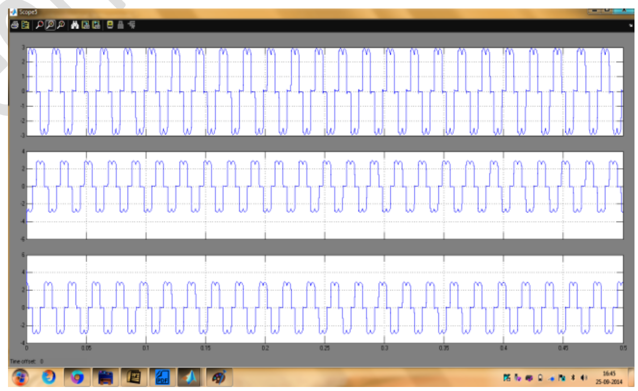

Fig.7 Three phase source current currents before compensation

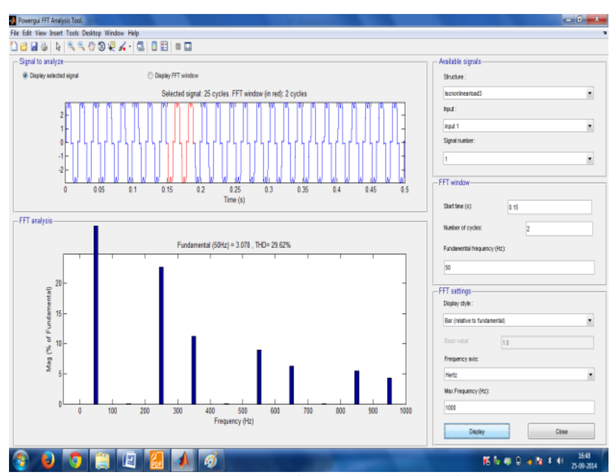

Fig.8 shows harmonics analysis of source current before compensation 29.62%

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Case-2 Fuzzy controlled based without APF in nonlinear load condition

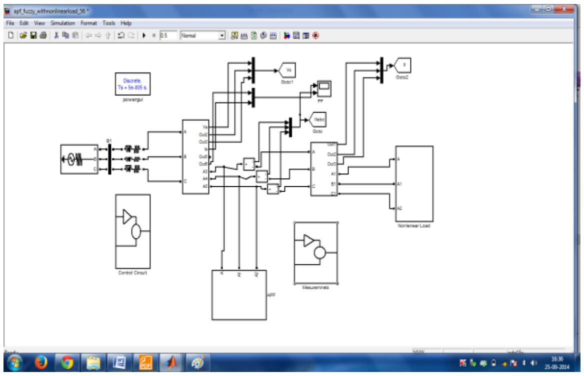

Fig.9 shows the Matlab/Simulink model of proposed converter after compensation

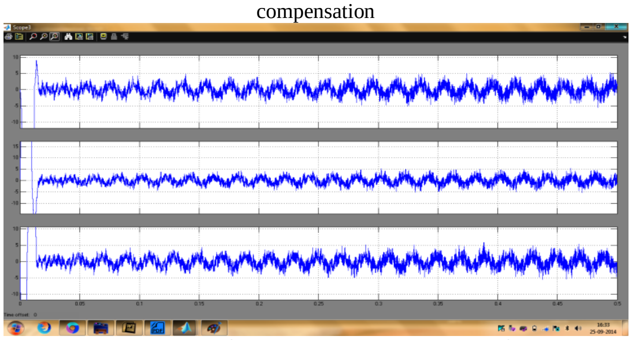

Fig.10 The reference harmonic currents identify

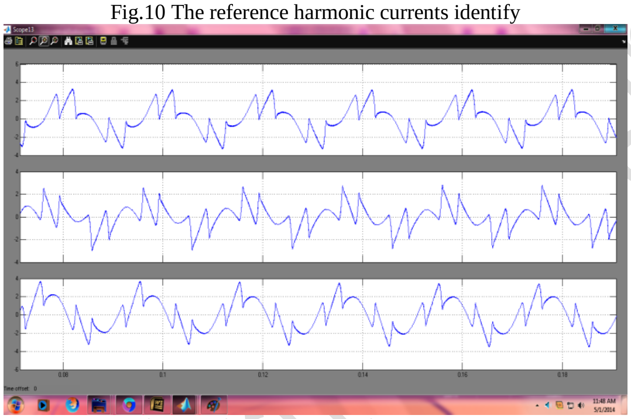

Fig .11 Conformed of injection and reference harmonic currents

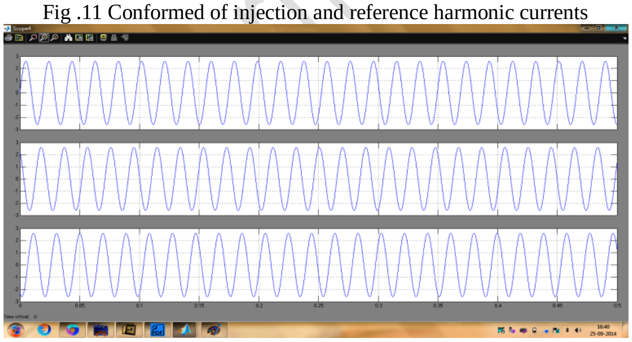

Fig.12 Three phase line currents after compensation

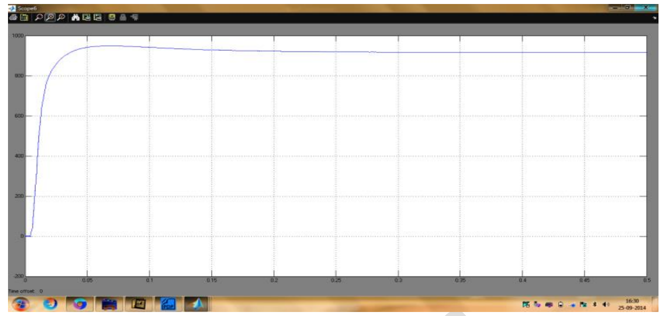

Fig.13 DC supply voltage source regulation of (SAPF)

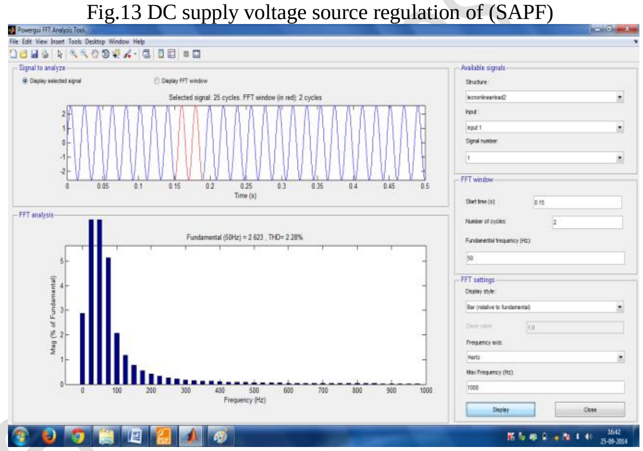

Fig.14 shows harmonics analysis of source current after compensation 2.28%

Case-3 PI controlled based APF in nonlinear load condition

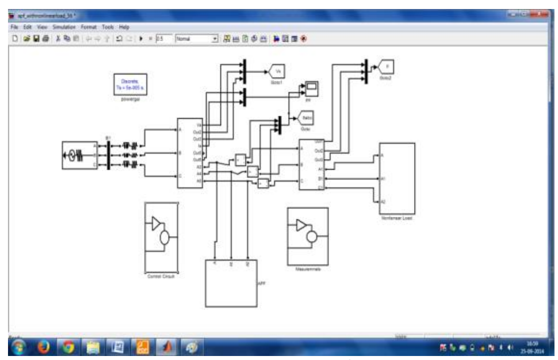

Fig.15 shows the Matlab/Simulink model of proposed converter with PI controller and nonlinear load

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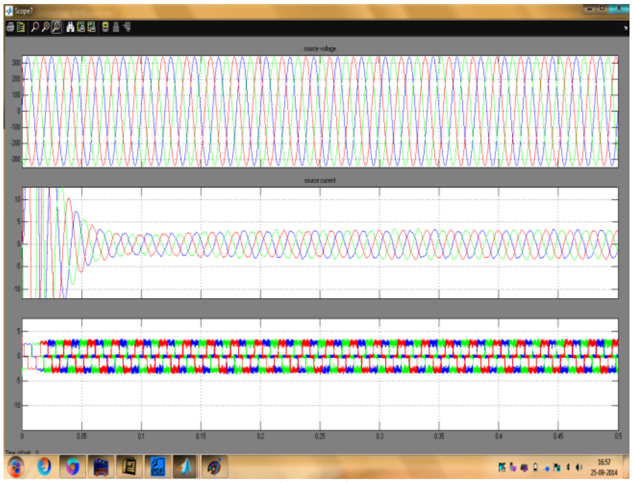

Fig.16 simulation output waveforms of source voltage, source current, load current with PI controller

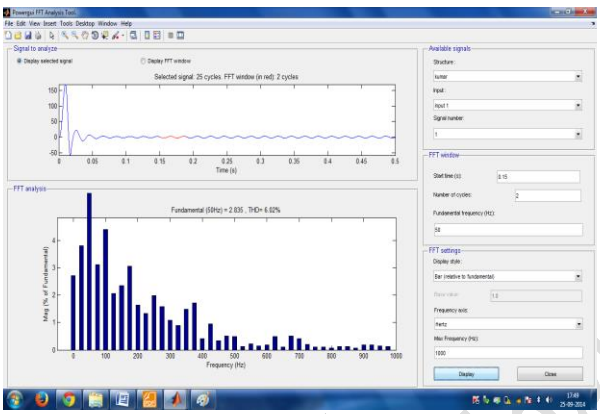

Fig.17 shows the harmonics analysis of source current with PI controller is 6.02%

VI. CONCLUSION

In this concept comparison of fuzzy controller and PI controller applying to reduce the harmonic content in proposed converter by using fuzzy we get the THD is 2.28% at that same conditions by using PI we get the THD is 6.02% so we prefer to reduce the harmonic content using fuzzy controller is better. The hysteresis band current technique was proposed for shunt active power filter to eliminate harmonics currents generated by nonlinear load. A fuzzy logic controller was used to regulate DC bus capacitor voltage of a shunt active power filter, and the *p q* theory to extract total harmonic currents pollution. The total harmonic distortion (THD) has been reduced clearly, that is within the limit of the harmonic standard recommendation. The results of simulation obtained demonstrate the effectiveness of the proposed system. The above all simulation results verified through Matlab/simulink software.

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