HARMONIC MITTIGATION FOR SHUNT ACTIVE FILTER USING PI AND FUZZY LOGIC CONTROLLERS

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Abstract- ***In present day life with the increase of non-linear loads in industrial, commercial and domestic facilities causes harmonic problems. Harmonics creates malfunctions in sensitive equipment, increase heat in the conductors, overvoltage by resonance and affects other customer loads connected at the Point of Common Coupling (PCC). Shunt Active Power Filter (APF) is designed and implemented for power quality improvements in terms of current harmonics and reactive-power compensation. The main objective is to mitigate the current harmonics and to analyze shunt active filters with fuzzy logic and PI controllers. H e r e active and reactive power(P-Q) and instantaneous active and reactive current (I_d-I_q)control strategies are considered. simulations will be carried out with PI and fuzzy controller for both control strategies under balanced voltage conditions. Instantaneous active and reactive current (I_d-I_q) control method with fuzzy logic controllers gives an outstanding performance under balanced voltage conditions.***

Index Terms-p-q theory,i_d-i_q method,reference current extraction,harmonics,PI controller,Fuzzy controller

I.INTRODUCTION

Now days ,the power quality in the distribution system is polluted due to unbalanced load currents. It gives distorted current at the point of common coupling. In modern power system the most important power quality issues are harmonic mitigation and reactive power compensation. Non linear loads represent a large percentage of the total loads. Under these conditions ,total harmonic distortion (THD) may become very high and dangerous for the system. The Power quality indices are governed by various standard regulations and recommendations such as IEEE-519.

Passive filters are achieved to mitigate harmonics for the past two decades .They have the disadvantage of potentially interacting adversely with the power system and it is important to check all possible system interactions when they are designed. They cannot operate successfully because of parallel resonance problem at a selected frequency.SAF is a active filter which is connected to shunt with the load and can work independently with of the system impedance characteristics. Active filters can be efficiently used to correct the power factor ,harmonics mitigation and reactive compensation, etc.

The basic principle of a shunt active filter is that it generates a current equal and opposite in polarity to the harmonic current drawn by the load and injects it to the PCC. The shunt active filter with the system configuration is taken as three phase bridge rectifier feeds RL load as non-linear load as shown in Fig.1.

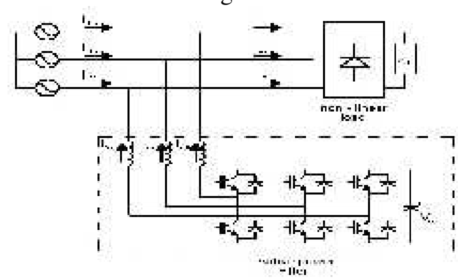


Fig..1 System configuration with SAF.

The efficiency of harmonic compensation depends on the type of control algorithm and to calculate the harmonics load current. The different control algorithms have been published for obtaining the APF reference current. These control algorithms are based on instantaneous reactive power algorithm (PQ), Synchronous detection method, Symmetrical component theory(SC), Instantaneous reactive and reactive power current component theory (dq),constant power factor Compensation theory, Perfect harmonics cancellation theory, etc.

This paper compares the performance of pq theory,dq theory using PI controller and Fuzzy logic controller of extracting reference current under balanced sinusoidal voltage conditions.

II.INSTANTANEOUS PQ THEORY

H.Akagi developed a instantaneous p-q method [1].In this theory active filter currents are obtained from the instantaneous active and reactive powers of the nonlinear load. The three phase voltages and currents in a-b-c coordinates are transformed into α-β-0 co-ordinates using clarke's transformation as shown in equation (1) and (2)

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} p_0 \\ p \\ q \end{bmatrix} = \begin{bmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

$$p = \bar{p} + \tilde{p} \quad (4)$$

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

The instantaneous active power (p), reactive power (q) and zero sequence power(p_0) as shown in equation (3).The ac component of active power and reactive power are utilized as the reference power. The reference currents in α-β are calculated by using equation (5)

$$\begin{bmatrix} i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} = \frac{1}{v_\alpha^2+v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} -\tilde{p} + \Delta\bar{p} \\ -q \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} i_{ca}^* \\ i_{cb}^* \\ i_{cc}^* \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} -i_0 \\ i_{c\alpha}^* \\ i_{c\beta}^* \end{bmatrix} \quad (6)$$

The losses in VSI due to switching of semiconductor devices so that additional average power required to compensate for the losses. The actual DC link capacitor voltage (Vdc) is compared with reference value and error is processed by controller These instantaneous current references to the hysteresis PWM current control are determined.

III I_d-I_q METHOD

In this method the compensation currents are obtained from instantaneous active and reactive current components i_{ld} and i_{lq} of the nonlinear load[3]. The mains voltages and load currents are to be transformed into αβ coordinates as given by equations below.

$$\begin{bmatrix} e_\alpha \\ e_\beta \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} e_u \\ e_v \\ e_w \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} i_{L\alpha} \\ i_{L\beta} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \quad (8)$$

$$\begin{bmatrix} p_L \\ q_L \end{bmatrix} = \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} p_L \\ q_L \end{bmatrix} \quad (9)$$

However, the *dq* load current components are derived from a synchronous reference frame Park's transformation, where 'θ' represents the instantaneous voltage vector angle, given in eq (10).

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix},$$

$$\theta = \tan^{-1}\left(\frac{e_\beta}{e_\alpha}\right) \quad (10)$$

Under balanced and sinusoidal conditions angle 'θ' is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and unbalance, therefore dθ/dt may not be constant over a mains period.

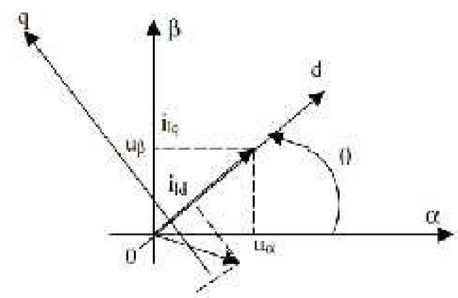


Figure.2 Graph

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \frac{1}{\sqrt{e_\alpha^2+e_\beta^2}} \begin{bmatrix} e_\alpha & e_\beta \\ -e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix}$$

$$e_d = |e_{dq}| = |e_{\alpha\beta}| = \sqrt{e_\alpha^2 + e_\beta^2} \quad (11)$$

the quadrature voltage component is always null, e_q =0, From equation (10) becomes instantaneous active and reactive load currents i_{ld} and i_{lq} decomposed into oscillatory and average terms.

$$i_{ld} = -\tilde{i}_{ld}+I_{Ld}, \quad i_{lq} = -\tilde{i}_{lq}+I_{Lq} \quad (12)$$

The first harmonic current of positive sequence is transformed to dc quantities. All higher order current harmonics including the first harmonic current of negative sequence, $il^{+-}dqnh + il^{-}dq1h$, are transformed to non-dc quantities and undergo a frequency shift in the spectra, and so, constitute the oscillatory current components. These assumptions are valid under balanced and sinusoidal mains voltage conditions. Eliminating the average current components by HPF's the currents that should be compensated are obtained, $i_{cd} = -\tilde{i}_{ld}$ and $i_{cq} = -\tilde{i}_{lq}$ .Finally, the compensating currents can be calculated by the following equations

$$\begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{e_\alpha^2 + e_\beta^2}} \begin{bmatrix} e_\alpha & -e_\beta \\ e_\beta & e_\alpha \end{bmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix} \quad (13)$$

$$\begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1 & \frac{-1}{2} & \frac{-1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}^T \begin{bmatrix} i_{c\alpha} \\ i_{c\beta} \end{bmatrix} \quad (14)$$

IV. CONSTRUCTION OF PI CONTROLLER

The internal structure of the control circuit as shown in Fig.3. The control scheme consists of a PI controller, a limiter, and a three phase sine wave generator for reference current and switching signal generation. The peak value of the reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a PI controller, which contributes to the zero steady error in tracking the reference current signal. The output of the PI controller is considered as the peak value of the supply current (Imax), which is composed of two components:

a. the fundamental active power component of the load current, and

b. the loss component of the APF; to maintain the average capacitor voltage at a constant value.

The peak value of the current (Imax) so obtained, is multiplied by the unit sine vectors in phase with the respective source voltages to obtain the reference compensating currents. These estimated reference currents (Isa*, Isb*, and Isc*) and the sensed actual currents (Isa, Isb, and Isc) are compared to a hysteresis band, which gives the error signal for the modulation technique. This error signal decides the operation of the converter switches. In this current control circuit configuration, the source/supply currents Isabc are made to follow the sinusoidal reference current Iabc, within a fixed hysteretic band. The width of the hysteresis window determines the source current pattern, its harmonic spectrum and the switching frequency of the devices. The DC link capacitor voltage is kept constant throughout the operating range of the converter. In this scheme, each phase of the converter is controlled independently. To increase the current of a particular phase, the lower switch of the converter associated with that particular phase is turned on. To decrease the current the upper switch of the respective converter phase is turned on. With this the potential and the feasibility of the PI controller can be realized.

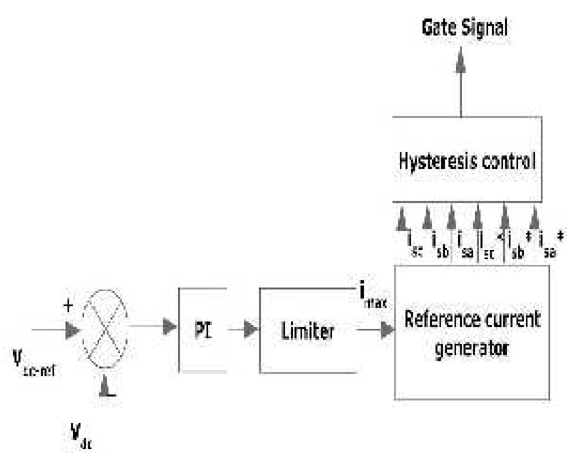


Figure.3 Conventional PI Controller

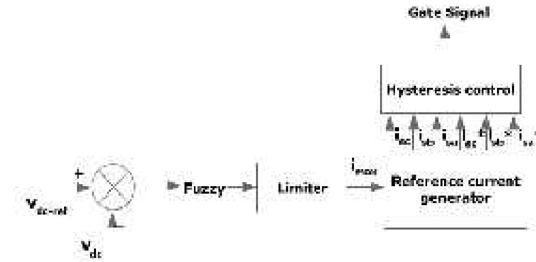


Fig..4 Internal Structure of Control Circuit

V. CONSTRUCTION OF FUZZY CONTROLLER

Fig. 4 shows the internal structure of the control circuit. The control scheme consists of a Fuzzy controller , a limiter, and a three phase sine wave generator for the generation of reference currents and switching signals. The peak value of the reference current is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to the zero steady error in tracking the reference current signal. Figure 4 shows the internal structure of the control circuit. The control scheme consists of Fuzzy controller, limiter, and three phase sine wave generator for reference current generation and generation of switching signals. The peak value of reference currents is estimated by regulating the DC link voltage. The actual capacitor voltage is compared with a set reference value. The error signal is then processed through a Fuzzy controller, which contributes to zero steady error in tracking the reference current signal. A fuzzy cotroller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, input voltage Vdc and the input reference voltage Vdc-ref have been placed of the angular velocity to be the input variables of the fuzzy logic controller. Then the output variable of the fuzzy logic controller is presented by the control Current Imax. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as:

NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big).The fuzzy controller is characterized as follows:

1. Seven fuzzy sets for each input and output;
2. Fuzzification using continuous universe of discourse;
3. Implication using Mamdani's ‘min’ operator;
4. De-fuzzification using the ‘centroid’ method.

Fuzzification: the process of converting a numerical variable (real number) convert to a linguistic variable (fuzzy number) is called fuzzification.

De-fuzzification: The rules of FLC generate required output in a linguistic variable (Fuzzy Number), according to real world requirements; linguistic variables have to be transformed to crisp output (Real number).

Database: The Database stores the definition of the membership Function required by fuzzifier and defuzzifier.

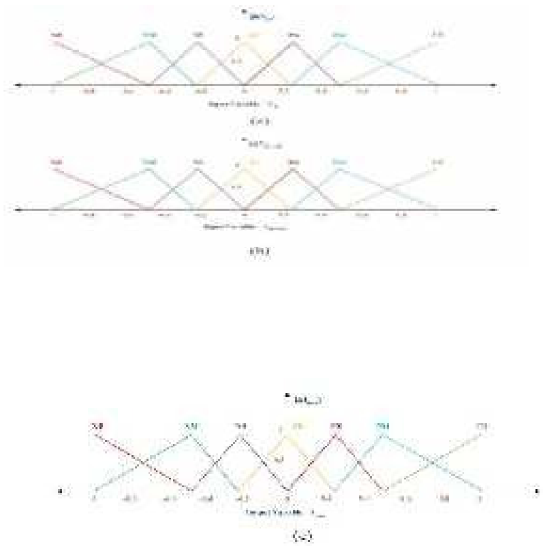


Fig.5. (a) Input V_{dc} normalized membership function;
(b) Input $V_{dc\text{-}ref}$ Normalized Membership Function;
(c) Output I_{max} Normalized Membership Function.

Table.1.Rule base

$V_{dc\text{-}ref}$ / V_{dc}	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

VI.REULTS AND DISCUSSION

All the simulations are carried out under MATLAB/Simulink and simpower toolbox for the development of SAF and its control algorithm. Simulation parameters are given inTable2.

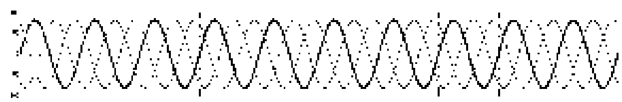
Table.2 Simlation parameters

System Source voltage	100V
System frequency	50Hz
DC link capacitor	35µF
Source Resistance	0.1Ω
Source Inductance	0.1mH
Resistive Load(three phase diode bridge rectifier)	60Ω
Series Inductor Load	20 mH

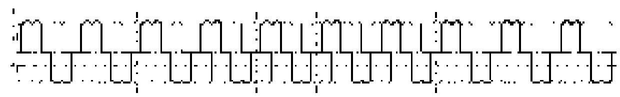
On observation PI controller fails to respond quickly because of non-linear nature in the system, but fuzzy supports with outstanding performance under any voltage conditions. Frankly fuzzy is finest controller in all the controllers, but it too have some drawbacks like redundancy and iteration problems. So one has to choose the membership function on the bases system complexity.

A .Performance of Instantaneous PQ algorithm with PI

Line voltage

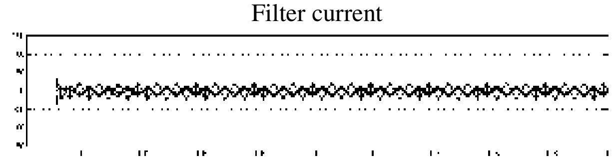


Load current

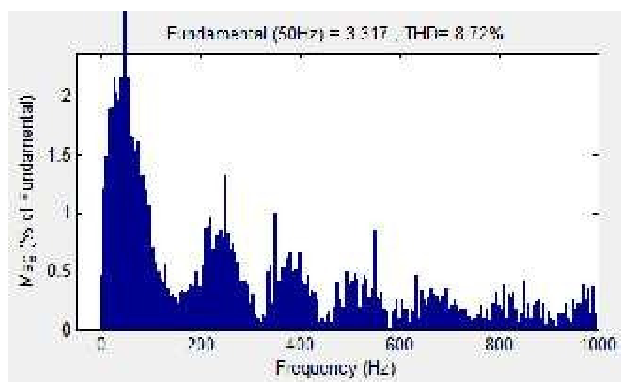


Line current

Filter current

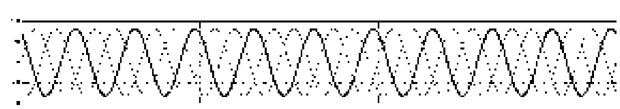


FFT Analysis

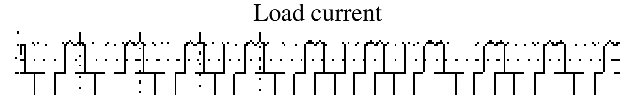


B. Performance of Instantaneous PQ algorithm with Fuzzy

Line voltage



Load current



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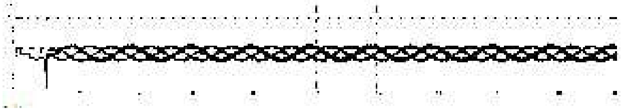

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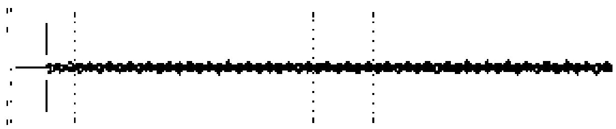

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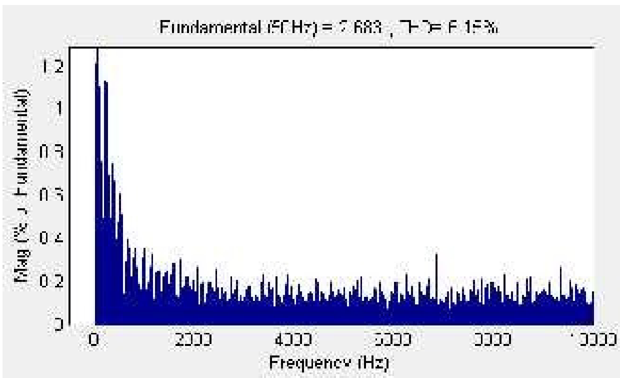
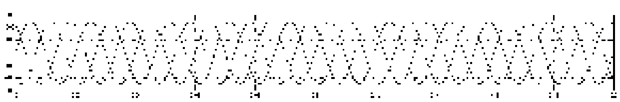


C . Performance of I_d-I_q method with PI controller

Line voltage



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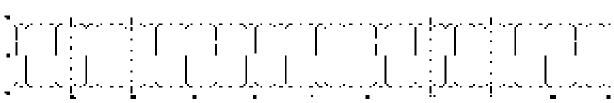

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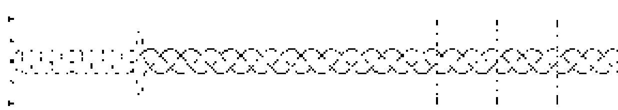

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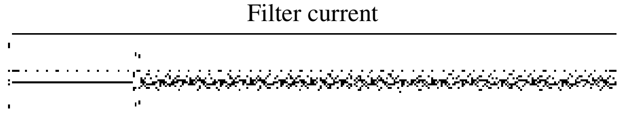

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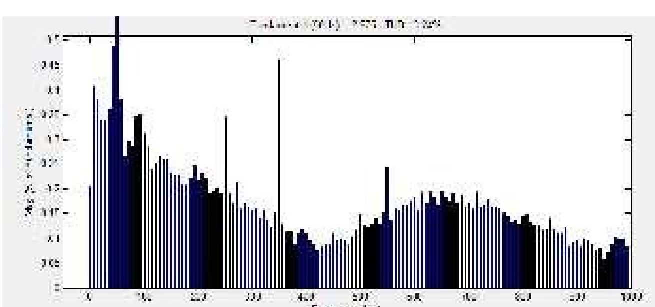
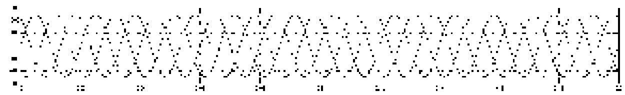
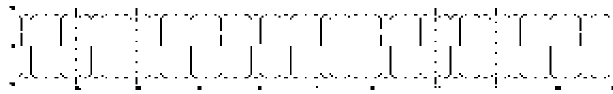


B. performance of I_d-I_q method with fuzzy

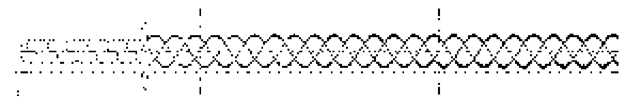
Line voltage



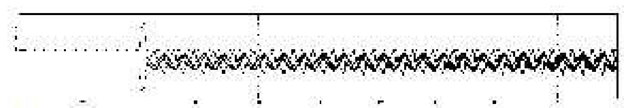
Load current



Line current



Filter current



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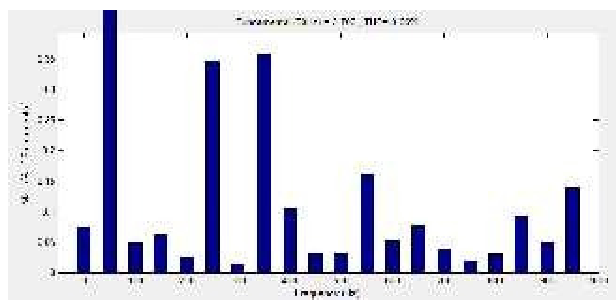

V.CONCLUSION

In the present paper two control algorithms are developed and verified with three phase three wire systems. Both the methods are compensate the current harmonics in 3 phase 3wire system. The compensation performance of the two techniques is almost similar under ideal balanced conditions and they satisfy IEEE-519 standard. It is observed that Fuzzy controller based I_d-I_q method is more sensitive than Instantaneous PQ algorithm under balanced sinusoidal main voltage conditions.

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