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Enhancement of a power quality by Shunt Active Power Filters Using Intelligence Techniques.

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Abstract

This paper presents the conventional application of shunt active power filter to suppressing harmonic pollution caused by nonlinear loads. Different controls strategies are used here are based on PI Fuzzy Logic Controller & ANN controller of the Shunt Active Filter with Hysteresis technique in detail. The control strategies are modeled using MATLAB/SIMULINK. The performance is also observed under influence of utility side disturbances such as harmonics, flicker and spikes. The simulation results are listed in comparison of different control strategies and for the verification of results.

***Keywords**: nonlinear loads; harmonic pollution; shunt active power filter; compensation; total harmonic distortion*.

1. INTRODUCTION

Any electrical power system consists of wide range of electrical, electronic and power electronic equipment in commercial and industrial applications. The quality of the power is affected by many factors like harmonic contamination, due to the increment of non-linear loads, such as large thyristor power converters, rectifiers, voltage and current flickering due to arc in arc furnaces, sag and swell due to the switching of the loads etc. Since most of the electronic equipment is nonlinear in nature these will induce harmonics in the system, which affect the sensitive loads to be fed from the system.

These problems are partially solved with the help of LC passive filters. However, this kind of filter cannot solve random variation in the load current wave form and voltage wave form. Active filters can resolve this problem. However, the cost of active filters is high. They are difficult to implement in large scale. Additionally, they also present lower efficiency than shunt passive filters. One of the many solutions is the use of a combined system of shunt and active series filters like unified power quality conditioner which aims at achieving a low cost under highly effective control.

The Active power filters (APFs) firstly developed by Akagi, provide better performances of harmonic elimination, and overcome the resonance problems. 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 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.

2.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. Instantaneous active and reactive power theory, (*p*–*q* theory) in time domain, can be used to identify the reference harmonic currents. Offers the advantage to choosing the disturbance harmonics with precision, speed and ease implementation. 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). The voltages and currents at the points of connections absorptive by nonlinear load can be converted by the components of Concordia into:

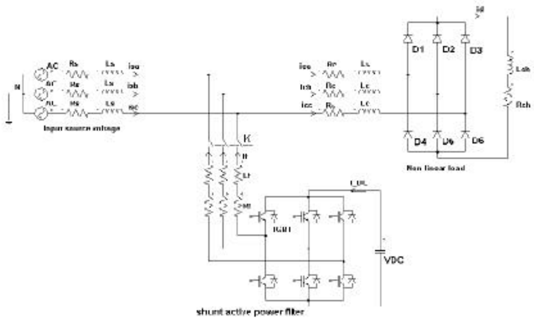


Fig.1. Simplified proposed of shunt active power filter

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

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

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

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

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:

$$p = \overline{p} + \widetilde{p} \qquad (4)$$

$$q = \overline{q} + \widetilde{q} \qquad (5)$$

$\overline{p}$, $\overline{q}$: DC average value of the instantaneous real and imaginary power respectively, its corresponds to the resulted
from the fundamental current and voltage from the power source to the load.

$\widetilde{p}$, $\widetilde{q}$: 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:

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

With :

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

Here, $\Delta = v_\alpha^2 + v_\beta^2$ (8)

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

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

Finally, we can calculate the reference harmonic current as:

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

The bloc diagram of (*p*–*q* theory), shown as fig. 2.

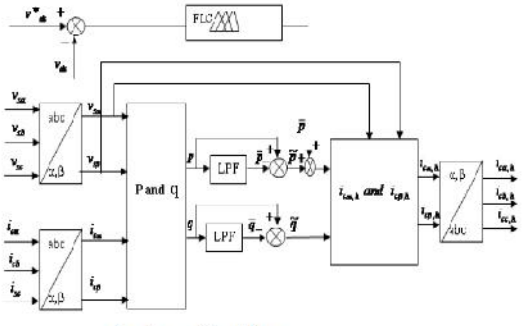


Fig. 2. p–q Algorithm

3. 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 (*iref*) obtained by using diagram bloc of (p–q theory), and the injection harmonic currents (*iinj*) of (SAPF), subtraction between (*iinj*) and (*iref*) , introduced in hysteresis band current to generate the gate pulses, The hysteresis control law is given as fig.3.

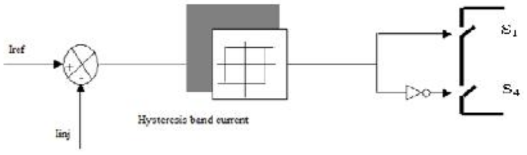


Fig. 3. Hysteresis band current control

The output hysteresis band current control (*S14*,*S36*,*S25*) are the gate pulses of six IGBTs switches :

$$S_{14}=\begin{cases}0 & \text{if } S_1 \text{ is closed and } S_4 \text{ is open}\\ 1 & \text{if } S_4 \text{ is closed and } S_1 \text{ is open}\end{cases} \qquad (11)$$

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

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

4. CONTROL OF DC VOLTAGE SOURCE OF (SAPF)

The advantage control of DC bus capacitor voltage source of (SAPF) arise 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. 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. 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 be compensated by the dc capacitor of inverter constructor of (SAPF). The changes of DC capacitor voltage from its reference most be regulate. 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, the block diagram of a control is illustrated by the figure. 4.

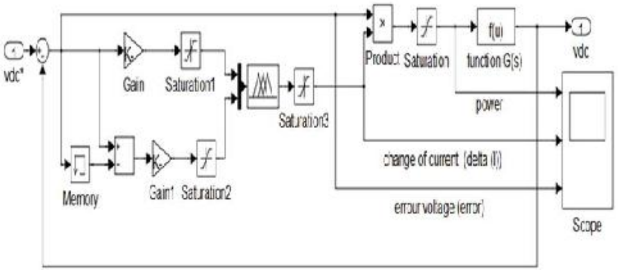
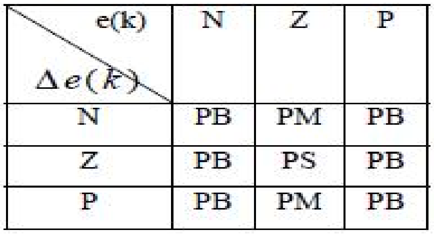


Figure 4: Control of DC link voltage source of SAPF

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*), 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.

TABLE I. THE FUZZY RULES



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

The real power absorbed by DC voltage can be expressed by:

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

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

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

After , The use of Laplace transform :

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

The transfert function is defined :

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

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

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

The change of the error can be calculated by :

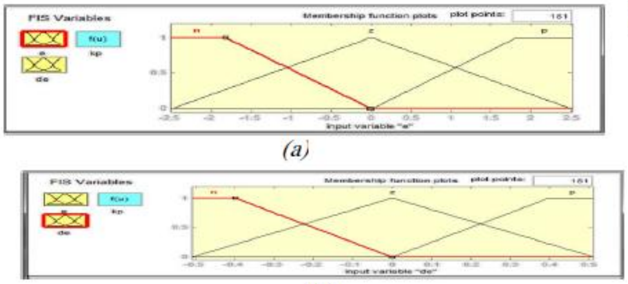
$$\Delta e(k) = (e(k) - e(k-1)) \cdot \beta \qquad (17)$$

α and β are the normalization coefficients [22].

The output of the fuzzy logic controller system is the change of the maximum current (k) , the Product block outputs $P(k)$ is the result of multiplying of the error dc voltage $e(k)$ and the output maximum current of FLC, obtained according to following equation:

$$P(k) = \mu(k) \cdot \Delta e(k) \qquad (18)$$

The membership functions of the fuzzy logic controller are shown in fig. 5.



(a)

(b)

Fig .5. Input membership function

5. PROPOSED CONTROL USING ANN

An ANN is essentially a cluster of suitably interconnected non-linear elements of very simple form that possess the ability of learning and adaptation. These networks are characterized by their topology, the way in which they communicate with their environment, the manner in which they are trained and their ability to process information. Their ease of use, inherent reliability and fault tolerance has made ANNs a viable medium for control. An alternative to fuzzy controllers in many cases, neural controllers share the need to replace hard controllers with intelligent controllers in order to increase control quality. A feed forward neural network works as compensation signal generator. The MAT LAB simulation file is shown in figure 6. & subsystem with ANN is shown in fig. 7.

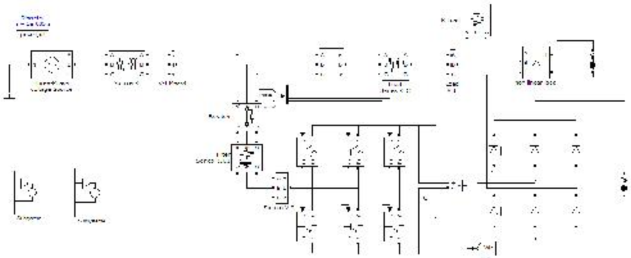


Figure6: APF with ANN in subsystem2.

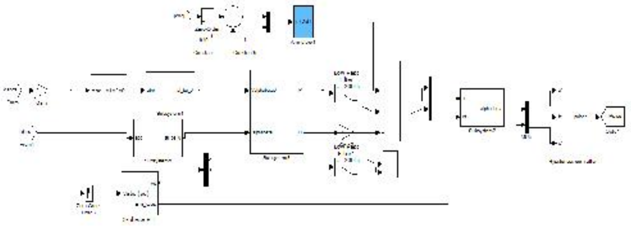


Figure 7: ANN simulation circuit.

6. SIMULATION RESULTS

Simulations test is performed to confirm the validity of the proposed system. The (SAPF) was designed to compensate

harmonics caused by nonlinear loads, the simulated results

were obtained by using hysteresis band current and ANN

controller was examined through Matlab/simulink. The nonlinear load is a three-phase full-bridge diode rectifier supplying a RL load. The hysteresis band current is used to

determine the switching time pulses of SAPF, the (p–q theory)

is used to determine the three phases reference harmonic currents and the ANN controller is used to regulate DC

bus capacitor voltage source of (SAPF).

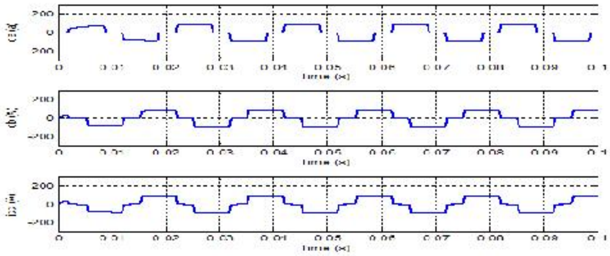


Figure 8: Three phase source current currents before compensation

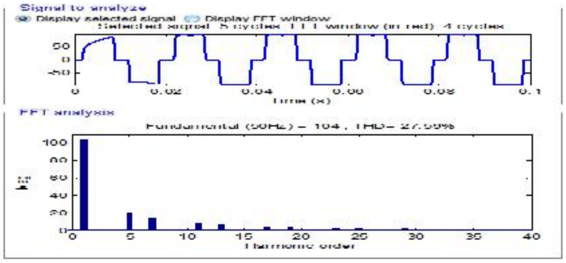


Figure 9: Spectrum harmonics analysis of source current before compensation

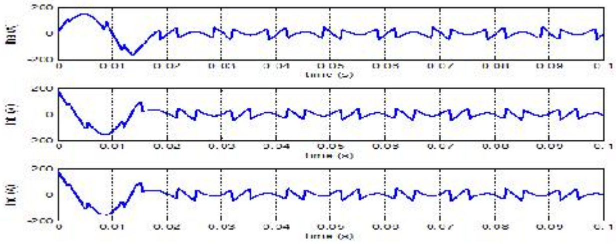


Figure.10: The reference harmonic currents identify

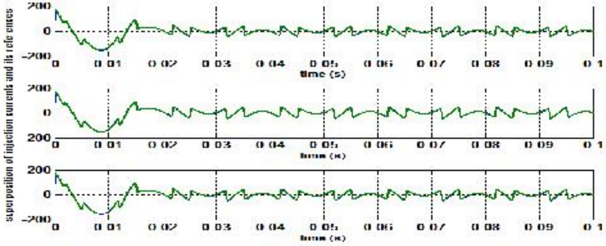


Figure 11: Conformed of injection and reference harmonic currents

The comparison between injection (*iinj*) and reference (*iref*) currents of (SAPF) shown as fig. 11. We can be seen a better conformation and superposition with excellent properties. The fig.12,13, show waveforms of the three phase source current currents and its spectrum harmonics analysis

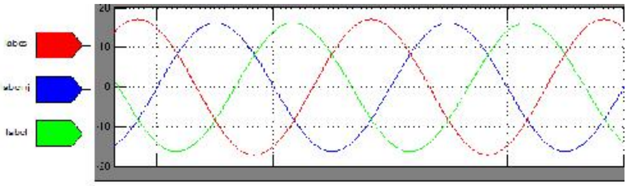


Fig .12. Three phase line currents after compensation

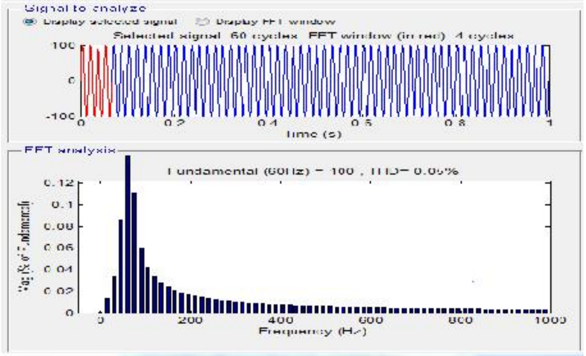


Figure 12: Spectrum harmonics analysis of source current after compensation

Spectrum harmonics analysis	% THD
Before Compensation	27.59%
After Compensation	0.05%

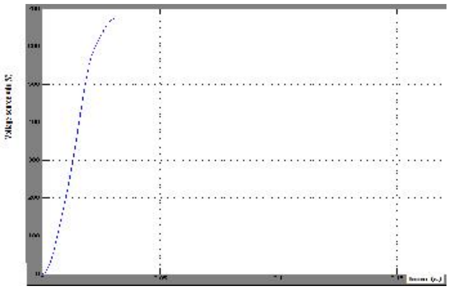


Figure 13: DC supply voltage source regulation of (SAPF)

7.CONCLUSION

In this paper, the hysteresis band current technique was proposed for shunt active power filter to eliminate harmonics currents generated by nonlinear load. A ANN 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. The results of simulation obtained demonstrate the effectiveness of the proposed system.

APPENDIX

Specifications circuit	parameters
Voltage source (Vrms Ph-Ph)	380 V
Source impedance	R=0.5 OHM, L=1mH
Input filter rectifier bridge	Rc=0.02Ω, Lc=0.1mH
Load rectifier bridge	Rch=5Ω, Lch=15mH
Output filter of SAPF	Rf=0.05Ω, Lf=0.9mH
DC-bus voltage	840 V

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