Comparative Study of Neuro Controller & Wavelet Transform for Shunt Active Filter in Reducing THD of a 3-Phase 4-Wire System

B.Suresh Kumar and K.Ramesh Reddy

Abstract—This paper presents an ANN & Wavelet controlled shunt active power filter used to compensate for total harmonic distortion in three-phase four-wire systems. The shunt active filter employs a simple method for the calculation of the reference compensation current based on Fast Fourier Transform. The presented Shunt Active Power filter is able to operate in balanced, unbalanced and Variable load conditions. Classic filters may not have satisfactory performance in fast varying conditions. But auto tuned active power filter gives better results for harmonic minimization, reactive power compensation and power factor improvement. The proposed auto tuned shunt active filter maintains the THD well within IEEE-519 standards. The proposed methodology is extensively tested for wide range of different Loads with Improved dynamic behavior of shunt active power filter using ANN & Wavelet controllers. The results are found to be quite satisfactory to mitigate harmonic Distortions, reactive power compensation and power factor correction thereby increase in Power Quality improvement and reduction in %THD.

Index Terms—Active power filter, Power quality improvement, Wavelet transform controller, ANN Controller, Power factor Correction, Reactive Power Compensation, THD.

I. INTRODUCTION

In a modern electrical distribution system, there has been a sudden increase of nonlinear loads, such as power supplies, rectifier equipment, domestic appliances, adjustable speed drives (ASD), etc. Power quality distortion has become a serious problem in electrical power systems due to the increase of nonlinear loads drawing non-sinusoidal currents. As the number of these loads increased, harmonics currents generated by these loads may become very significant. These harmonics can lead to a variety of different power system problems including the distorted voltage waveforms, equipment overheating, malfunction in system protection, excessive neutral currents, light flicker, inaccurate power flow metering, etc. They also reduce efficiency by drawing reactive current component from the distribution network. To reduce harmonic distortion and power factor improvement, capacitors are employed as passive filters. But they have the drawback of bulky size, component aging, resonance and fixed compensation performance.

Active filters have been widely used for harmonic

mitigation as well as reactive power compensation, load balancing, voltage regulation, and voltage flicker compensation. In three-phase four-wire systems with nonlinear loads a high level of harmonic currents has been enrolled both in the three line conductors and more significantly in the neutral wire. Unbalanced loads also results in further declination of the supply quality. Various harmonic mitigation techniques have been proposed to reduce the effect of harmonics. These techniques include phase multiplication, passive filters, active power filters (APFs), and harmonic injection. One of the most popular APFs is the shunt active power filter. It is mainly a current source, connected in parallel with the non-linear loads. Conventionally, a shunt APF is controlled in such a way as to inject harmonic and reactive compensation currents based on calculated reference currents. The injected currents are meant to cancel the harmonic and reactive currents drawn by the nonlinear loads.

II. BASIC COMPENSATION PRINCIPLE

Fig.1 shows the basic compensation principle of the shunt APF. A current controlled voltage source inverter with necessary passive components is used as an APF [8]. It is controlled to draw/supply a compensated current from/to the utility, such that it eliminates reactive and harmonic currents of the non-linear load. Thus, the resulting total current drawn from the ac mains is sinusoidal. Ideally, the APF [6] needs to generate just enough reactive and harmonic current to compensate the non-linear loads in the line

Fig. 1. Basic compensation principle of shunt APF

Fig. 2. Basic compensation principle of shunt APF

Manuscript received on November15, 2011; revised July 19, 2011.

B. Suresh Kumar EEE Dept, CBIT, Hyderabad-75 (mail: bskbus@gmail.com).

K. Ramesh Reddy is with EEE Department, GNITS, Hyderabad (Mail: kollirameshreddy@yahoo.co.in).

Control system description for Shunt APF:

The control system for shunt APF could be divided into two main stages. In the first stage the reference compensating current has to be determined, while in the second stage the derivation of the switching function for the filter inverter circuit is computed.

Reference Compensation Current Calculation:

The reference compensation current is determined mainly using the information about both the fundamental and the harmonic content of the measured load current. Several methods have been proposed in the literature for reference compensation current computation. These methods depend on either time domain or frequency domain analysis. In this paper the method utilized for reference compensation current calculation depends on Fast Fourier Transform (FFT), sort of frequency domain analysis. FFT is used to extract the magnitude of the fundamental component of the load current from which the reference compensation current will be computed.

The following equations describe the procedure used for reference compensation current calculations.

$$i_{load} = i_{loadfund} + i_{harmonics} \rightarrow (1)$$

$$i_{loadfund} = |i_{loadfund}| \sin \omega t \rightarrow (2)$$

$$i_{load} = \frac{a_0}{2} + \sum_{n=1}^{\infty} [a_n \cos(n\omega t) + b_n \sin(n\omega t)]$$

$$a_0 = \frac{1}{\pi} \int_{-\pi}^{\pi} i_{load}(t) dt$$

$$a_n = \frac{1}{\pi} \int_{-\pi}^{\pi} i_{load}(t) \cos(nt) dt$$

$$b_n = \frac{1}{\pi} \int_{-\pi}^{\pi} i_{load}(t) \sin(nt) dt$$

Thus, the fundamental component magnitude of load current

$$i_{loadfund} = \sqrt{a_n^2 + b_n^2}$$

The amplitude of the reference supply current is given by

$$i_s^* = (i_{loadfund} + i_{dc}) \sin \omega t \rightarrow (3)$$

where i_{dc} is the current responsible for compensating of the dc losses due to the change in the dc capacitor voltage. Then taking the sine wave template from the supply voltage, the reference supply current will be

$$i_s^* = (i_{loadfund} + i_{dc}) \sin \omega t \rightarrow (4)$$

And From equation (1) & (4)

$$i_f^* = i_s^* - i_{load} \rightarrow (5)$$

Therefore

$$i_f^* = (|i_{loadfund}| + i_{dc}) \sin \omega t - (i_{loadfund} + i_{harmonics})$$

$$i_f^* = i_{dc} \sin \omega t - i_{harmonics} \rightarrow (6)$$

Summarizes the control strategy for shunt active power filter

Fig. 3. The control strategy for Shunt Active Power Filter

III. WAVELETS

Wavelet analysis is a new development in the area of applied mathematics. Fourier analysis is ideal for studying stationary data (data whose statistical properties are invariant over time) but is not well suited for studying data with transient events that cannot - be statistically predicted from the data's past. Wavelets were designed with such non-stationary data. The proposed wavelet is Biorthogonal Wavelets 2.2 [7] orthogonally of vectors and functions allow us to represent general vectors and functions in terms of a set of complete orthogonal vectors and functions, respectively.

IV. BIORTHOGONAL WAVELET SYSTEMS

In many filtering applications we need filters with symmetrical coefficients to achieve linear phase. None of the orthogonal wavelet systems except Haar are having symmetrical coefficients. But Haar is too inadequate for many practical applications. Biorthogonal wavelet system can be designed to have this property. That is our motivation for designing such wavelet system. Non-zero coefficients in analysis filters and synthesis filters are not same. [7]

$$\text{Let } \phi(t) = \sum_{k=0}^{N-1} h(k) \sqrt{2} \phi(2t-k) \quad (1)$$

And its translates form the primal scaling function basis and corresponding space be v_0 .

$$\text{Let } \tilde{\phi}(t) = \sum_{k=0}^{N-1} \tilde{h}(k) \sqrt{2} \tilde{\phi}(2t-k) \quad (2)$$

And translates form the dual scaling function basis and corresponding space be $\tilde{v}_0$. This means that $\phi(t)$ and its translates are not orthogonal among themselves but orthogonal to translates of $\tilde{\phi}(t)$ (except one basis function as in vector space) such that

$$\phi(t-k) \perp \tilde{\phi}(t-m) \quad \text{For every } k \neq m$$

This in turn means

$$\int \phi(t-k) \tilde{\phi}(t-m) dt = 0 \quad \text{For } k \neq m$$

Also we need that, like in vector space.

Projecting $\phi(t-k)$ onto $\tilde{\phi}(t-k)$ should result in unity. That is

$\int \varphi(t-k)\tilde{\varphi}(t-k)dt=1$ For every k these two conditions together we put as:

$$\int \varphi(t)\tilde{\varphi}(t-k)dt = \delta_{k,0} \quad (3)$$

Like scaling functions. Wavelet function also follows the scaling relation given by

$$\psi(t) = \sum_k g(k)\sqrt{2}\varphi(2t-k)$$

and

$$\tilde{\psi}(t) = \sum_k g(k)\sqrt{2}\tilde{\varphi}(2t-k) \quad (4)$$

In orthogonal wavelet system, $\varphi(t)$ is orthogonal to $\psi(t)$ and its translates. In biorthogonal system our requirement is that $\varphi(t)$ be orthogonal to $\tilde{\psi}(t)$ and its translates. Similarly $\tilde{\varphi}(t)$ must be orthogonal to $\psi(t)$ and its translates. Since $\varphi(t) \perp \tilde{\psi}(t)$, $\tilde{\psi}(t)$ can be written as:

$$\tilde{\psi}(t) = \sum_{k=0}^{N-1} (-1)^n h(N-k-1)\tilde{\varphi}(2t-k) \quad (5)$$

(The condition $\varphi(t) \perp \tilde{\psi}(t)$ relates $g(k)$ with $h(k)$. $g(k)$ becomes alternate flip of $h(k)$ the derivation of the result follows in the same line as in orthogonal wavelets.

Similarly, since $\tilde{\varphi}(t) \perp \psi(t)$,

$$\psi(t) = \sum_{k=0}^{N-1} (-1)^n \tilde{h}(N-k-1)\varphi(2t-k) \quad (6)$$

Let $\psi(t)$ and its translates span the space W_0 and $\tilde{\psi}(t)$ and its translates span the space $\tilde{W}_0$. Like primal and dual scaling functions, $\psi(t)$ is not orthogonal to its own translates but are orthogonal to translates of $\tilde{\psi}(t)$, that is,

$$\int \psi(t-k)\tilde{\psi}(t-m)dt = \delta_{k-m} \quad (7)$$

In orthogonal wavelet system is orthogonal to any scaled version of itself and its translates, that is,

$$\int \psi(t-k)2^{j/2}\tilde{\psi}(2^j t-m)dt = \delta_{j,k-m} \quad (8)$$

The integral is zero except when $j=0$ and $k=m$. when $j=0$ and $k=m$, the integral becomes

$$\int \psi(t)\psi(t)dt = 1$$

So in biorthogonal system, the most general equation connecting $\psi(t)$ and $\tilde{\psi}(t)$ is:

$$\int \psi_{j,k}(t)\tilde{\psi}_{j',k'}(t)dt = \delta_{j-j'}\delta_{k-k'} \quad (9)$$

Now, we conclude the discussion by putting all [the relations in biorthogonal wavelet systems in one place. We have the following relationships:

$$1. v_{-1} \subset v_0 \subset v_1 \subset \dots \subset v_\infty$$

$$2. \tilde{v}_{-1} \subset \tilde{v}_0 \subset \tilde{v}_1 \subset \tilde{v}_2 \subset \dots \subset \tilde{v}_\infty$$

where

$$v_j = \text{span}_k \{2^{j/2}\varphi(2^j t-k)\} \text{ and } \tilde{v}_j = \text{span}_k \{2^{j/2}\tilde{\varphi}(2^j t-k)\}$$

In orthogonal wavelet system we have v_j orthogonal to w_j . I

3. But in biorthogonal system, v_j is orthogonal only to $\tilde{w}_j$. Similarly, $\tilde{v}_j$ is orthogonal only to w_j .

$$4. w_k \perp \tilde{w}_j.$$

Math symbols:

1. $\subset$ - Subset 2. $\emptyset$ -empty set or $\varnothing$ \varnothing

3. ψ - Psi

4. $\sim$ -similar to

5. $\perp$ -perpendicular

6. $\sum$ -sum

7. Infinity- ∞

V. NEURAL CONTROLLER

This paper proposes the use of an artificial neural network (ANN) technique the neural controller uses feed forward back propagation algorithm. The inputs to the neural controller for the shunt active filter. The proposed method uses ANN algorithm to compute the harmonic current and reactive power for the nonlinear loads. With the use of this ANN controller, the shunt active filter can be made adaptive to variations in nonlinear load currents. It can also compensate for unbalanced nonlinear load currents. It can also correct power factor of the supply side near to unity. It also has the capability to regulate the dc capacitor voltage at the desired level. Computer simulations are carried out to verify an active filter performance.

The neural controller uses feed forward back propagation algorithm. The inputs to the neural controller are the filter error and its derivative and output is the conduction time of the switches. These inputs and outputs obtained are given to neural network tool box where the training process takes place using back propagation algorithm (training of the data until minimum error is obtained) and the outputs are given as pulses to IGBT's in the shunt active filter. In the shunt active filter which acts as a voltage source converter the capacitor voltage is maintained constant and the inductor current is made equal in magnitude but opposite in phase to that of the load current consisting of harmonics. So, the harmonics injected by the load current in the supply current are cancelled by the negative harmonics injected by the filter output current thereby, resulting in the harmonic reduction [9]-[10].

The following diagrams represent the internal structure and operation of presented ANN controller for shunt active filter.

Fig. 6. the internal structure of presented ANN controller

Fig.7. Simulink model of shunt active power filter using ANN & Wavelet controllers with balanced, unbalanced and variable nonlinear models.

VI. Simulation Parameters:

TABLE: 2. PARAMETERS IN CASE OF BALANCED LOAD

V_s	170v
L_s	1mH
L_f	4mH
L_r	2mH
Load	$R_r=50\Omega$

TABLE: 3. PARAMETERS IN CASE OF UNBALANCED LOAD

V_s	170v
L_s	1mH
L_f	4mH
L_r	2mH
Loads	Load1: $R_r=50\Omega$ Load2: $R_2=15\Omega$ Load3: $R_3=15\Omega$, $L_3=0.1H$

TABLE: 4. PARAMETERS IN CASE OF VARIABLE LOAD

V_s	170v
L_s	1mH
L_f	4mH
L_r	1mH
Variable Load	$V_{dc}=120v, R=1\Omega, L=20mH$

VI. SIMULATION RESULTS

I_L -Load Current, I_F -Filter Current & I_S -Source Current

Fig: 7 Wave forms of balanced non linear load under ANN control

Fig: 8 Wave forms of unbalanced non linear load under ANN control

Fig.9. Wave forms of variable non linear load under ANN control

Fig.10. Wave forms of balanced non linear load under Wavelet control

Fig.11. Wave forms of unbalanced non linear load under Wavelet control

Fig.12. Wave forms of Variable non linear load under Wavelet control

Fig.13.FFT Analysis for ANN & wavelet controllers:

From the above fig 13. shows that FFT analysis using ANN and Wavelet for the balanced, unbalanced and dynamic loads.

TABLE: 6. RESULTS WITH BALANCED LOAD

CONTROLScheme	With Filter			With Out Filter		
	%THD	P.f	Reactive Power (Vars)	%THD	P.f	Reactive Power (Vars)
ANN	1.42	0.992	88.60	94.96	0.662	4177
Wavelet	0.60	0.993	8441	94.52	0.6618	4181

TABLE: 7 RESULTS WITH UNBALANCED LOAD

CONTROLScheme	With Filter			With Out Filter		
	%THD	P.f	Reactive Power (Vars)	%THD	P.f	Reactive Power (Vars)
ANN	1.35	0.973	34.82	99.64	0.652	31.67
Wavelet	0.67	0.984	29.41	98.35	0.734	35.83

TABLE:8 RESULTS WITH DYNAMIC OR VARIABLE LOAD

CONTROLScheme	With Filter			With Out Filter		
	%THD	P.f	Reactive Power (Vars)	%THD	P.f	Reactive Power (Vars)
ANN	1.42	0.992	88.60	94.96	0.662	4177
Wavelet	0.60	0.993	8441	94.52	0.6618	4181

VII. CONCLUSION

The ANN and Wavelet controllers of Shunt Active Power filter are designed. The proposed control technique is found satisfactory to mitigate harmonics from utility current especially under variable load condition. Thus, the resulting total current drawn from the ac mains is sinusoidal. ANN and Wavelet controllers improve the overall control system performance over other conventional controller. The validity of the presented controllers was proved by simulation of a three phase four wire test system under balanced, unbalanced and variable loading conditions. The proposed shunt active filter compensate for balance and unbalanced nonlinear load currents, adapt itself to compensate variations in non linear load currents, and correct power factor of the supply side near to unity. Proposed APF topology limits THD percentage of source current under limits of IEEE-519 standard. THD percentage of source current under ANN and Wavelet controllers are compared. It has also been observed that reactive power compensation has improved leading to power factor improvement. These comparisons conclude that **Wavelet controller is better choice than ANN controller.**

ACKNOWLEDGMENT

My sincere and heartfelt thanks to my guide Dr. Kolli Ramesh Reddy, Dean & Head, Dept. of EEE, G.Narayanamma Institute of Technology & Science, Shaikpet, HYDERABAD-500 008, Andhra Pradesh, INDIA for his valuable guidance, sustained interest,

constructive criticism, generous help and constant encouragement at every stage of this endeavor.

My heartfelt thanks to Mrs. Dr. K. Krishnaveni, Professor and Head, Department of Electrical Engineering Chaitanya Bharathi Institute of Technology, Hyderabad.

I gratefully acknowledge the valuable suggestions given by our Department Faculty members.

Last but not least Special heartfelt thanks to my family members particularly my wife, daughter and mother & father gave tremendous support throughout the work

REFERENCES

- [1] B. K. Bose, Expert Systems, Fuzzy Logic and Neural Network Application in Power Electronics and Motion Control. Piscataway, NJ: IEEE Press, 1999, ch.11.
- [2] V. S. C. Raviraj and P. C. Sen, "Comparative study of proportional integral, sliding mode, and fuzzy logic controllers for power converters," IEEE Trans. Ind. Appl., vol. 33, no. 2, pp. 518-524, Mar./Apr. 1997.
- [3] C. N. Bhende, S. Mishra, and S. K. Jain, "TS-Fuzzy-Controlled Active Power Filter for Load Compensation", IEEE Transactions on Power Delivery, Vol. 21, No. 3, July. 2006.
- [4] "Active filter for power quality improvement by artificial neural networks technique" by M.A.Farahat, A.Zobah, Zagazig University.
- [5] G. K. Singh, "Power system harmonics research: a survey" European Transactions on Electrical Power, 2009 Page(s):151 – 172.
- [6] A. Emadi, A. Nasiri, S. Bekiarov, Uninterruptible Power Supplies and Active Filters. CRC Press, 2005, ch. 2.

- [7] "Insicght into Wavelets-From Theory to Practice" by K.P.Soman & K.I Ramachandran
- [8] S. Rechka, E. Ngandui, Jianhong Xu; P. Sicard, "A comparative study of harmonic detection algorithms for active filters and hybrid active filters" IEEE 33rd Annual Power Electronics Specialists Conference, 2002. Volume 1, Page(s): 357 - 363.
- [9] J. S. Setiadji and H. H. Tumbelaka, "Simulation of Active Filtering Applied to A Computer Centre," Journal Technique Electro, vol. 2, pp 105-109, September 2002.
- [10] "Auto Tuned Robust Active Power Filter for Power Quality Improvement under Fast Load Variation" by S. S. Mortazavi, R. Kianinezhad, A. Ghasem

B. Suresh Kumar, Asst.Professor in EEEDept, CBIT, Gandipet, and Hyderabad-75. Previously worked as Asst.Professor at QIS College of Engineering and Prakasam Engineering colleges at prakasam district andhrapradesh India. I have published the various papers on power quality area.at present I am doing research at jntuh Hyderabad.

Kolli Ramesh Reddy, Dean & Head, Dept.of EEE, G.Narayanamma Institute of Technology & Science, Shaikpet, HYDERABAD-500 008, Andhra Pradesh, INDIA