

A Simulation of Active Shunt Filter with Neural Network Control to Improve Voltage Profile and Power Quality

Negar Mehran Far*

Master of Electrical Engineering - Power Engineering
Shahid Chamran University of Ahvaz - Ahvaz - Iran
negarmehranfar@gmail.com

Dr. Mahmoud Jorabian

Full Professor - Doctor of Electrical Engineering
Faculty of Shahid Chamran University of Ahva

Abstract- Nonlinear loads lead to the creation of harmonics in power grids and a reduction in power quality. Furthermore, the nonlinear loads are not constant and change randomly. Since the quality of electric power manufactured in any country is a measure of the industrial progress of that country, methods are needed to reduce the harmonics of the power grid. Passive filters are normally used to reduce current harmonics during connecting nonlinear loads to the power grid. Whereas these filters have problems such as large aging size, resonance, and constant compensation. The progress of power electronic elements and the reduction of production cost of these elements have made active filters a suitable option for reducing harmonics and compensating reactive power to improve power quality. The purpose of this paper is to simulate active shunt filters through neural network control to improve voltage profile and power quality. The simulation results showed that the reactive power received from the source reaches "0" after one cycle, which leads to a power factor of "1" and the ideal performance of the adaptive shunt active filter with load changes. On the other hand, the dynamic performance of the filter is also ideally improved. The THD percentage of the source current is always less than five during load changes, which shows the ideal performance of the adaptive shunt active filter in the steady state.

Keywords- Voltage profile, Power quality, Active shunt filter simulation, Neural network control.

1. Introduction

In the past, the increasing application of nonlinear loads has caused many problems in the field of power quality. These problems include (i) Current harmonics, (ii) Low power factor, and (iii) Increased neutral currents. Nonlinear loads act as sources that inject harmonic currents into the power grids at the PCC point. The injection of current harmonics into the power grid causes a voltage drop in the impedance of the source, and eventually, voltage distortions occur in the PCC. Consumers at the PCC point receive the distorted source voltage. It can lead to excessive heat in the insulation of equipment and cables and disturbance in the power factor of capacitors, motors, and transformers. Also, the unfavorable performance of protective devices causes improper operation of fuses and breakers and disruption of telecommunication lines [1]. Ignoring harmonics in the grid and compensating them may cause resonance in a certain harmonic between the power factor correction capacitors and the source inductance. It also can lead to the creation of high fluctuating currents, and as a result, high voltage harmonics and malfunction of performance of power electronics

equipment in the shortest possible time. Hence, it is vital to install compensating devices to eliminate current harmonics produced by nonlinear loads [2]. In the past, passive filters were used to keep harmonics within a reasonable range. But these filters included disadvantages such as large resonance size and fixed compensation. So, the passive filter could not completely solve the problem of harmonics [3]. With the improvement of the capabilities of switching elements and digital processors, static compensating devices have gained much attention. Active filters are among the tools that have been used in recent years to reduce the power systems' harmonics. Active filters are used in two ways: (i) Series (voltage) and (ii) Parallel (current). Due to some advantages, an active shunt filter based on Voltage Source Inverter (VSI) has attracted attention in recent years. Active shunt filter based on VSI consists of three basic parts. Part I contains the reference signal detector, which its task is to separate the harmonic signal from the load current. Part II includes the harmonic injection current source and part III includes the control circuit [4]. In fact, part II is a voltage source inverter. The control circuit consists of two parts: (a) The voltage

controller whose role is to stabilize the DC link capacitor voltage and (b) The current controller which, with proper operation, causes the source or filter current to follow the reference signal without error [5]. Active shunt filter with PI controller does not provide good dynamic performance and durability. Especially when the load is variable, it cannot adapt to its changes. Thus, this study focuses on improving the dynamic performance and impedance of the active filter and increasing its resistance to load changes [6]. Artificial intelligence has been widely developed in the last four decades and is popular for its ability to control complex systems under difficult conditions. Techniques such as (i) Artificial intelligence, (ii) Fuzzy logic (iii) Neural networks, (iv) Genetic algorithm, (v) Violet theory,

and (vi) Optimization methods have been used to improve power quality since 1980, which have brought good results [7]. In the present paper, neural networks have been used to accurately estimate the nonlinear load current, increase the compensation rate, and adapt the active filter to fast load changes. Here, ADALINE neural network was used and the adaptive shunt active filter was designed based on the model and type of neural network presented by Tey in 2005.

Structure of an adaptive shunt active filter with the neural network controller

Fig. 1. Illustrates the structure of the adaptive shunt active filter with the neural network controller

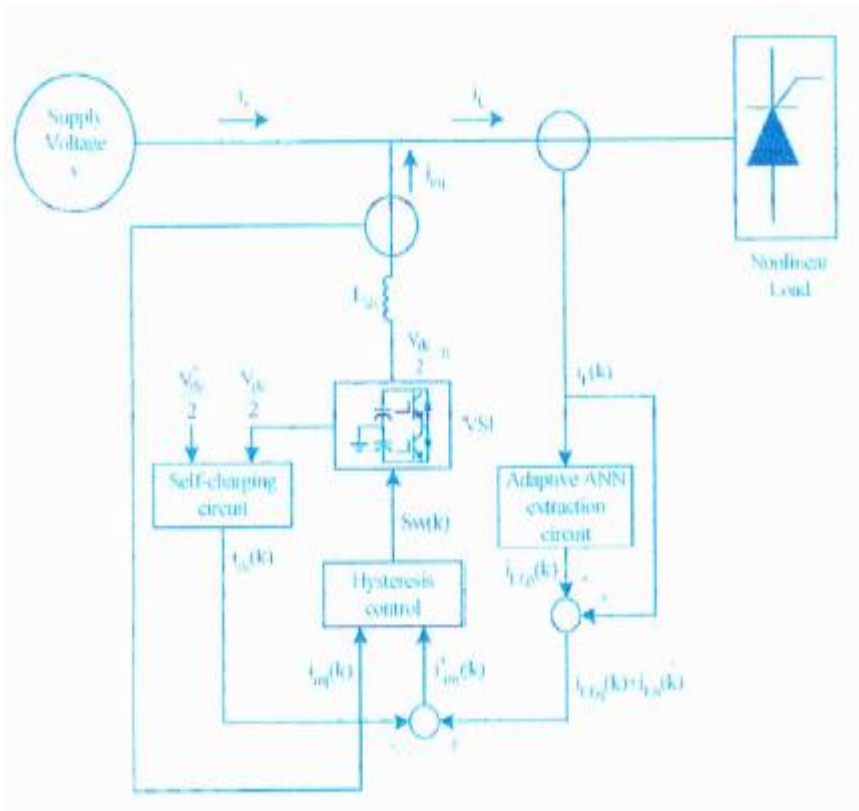


Fig. 1. General structure of adaptive shunt active filter

The components of this circuit have four parts, including:

- I. Adaptive ANN extraction circuit
- II. Self-Charging circuit
- III. Hysteresis control
- IV. Injection circuit (including VSI and low-pass filter)

An Adaptive ANN extraction circuit

This circuit is an estimate of inductor current $i_L(k)$ and presents $\bar{i}_L(k)$ from the nonlinear load current as the sum of Sin and Cos components with proportional coefficients in the form of the following Equations:

$$\begin{aligned}
 i_L(k) &= \sum_{n=1,2,3,\dots}^N [w_{1n} \sin(nk\omega\Delta t) \\
 &\quad + w_{2n} \cos(nk\omega\Delta t)] \\
 &= w_{11} \sin(k\omega\Delta t) \\
 &\quad + w_{21n} \sin(k\omega\Delta t) \\
 &\quad + \sum_{n=1,2,3,\dots}^N [w_{1n} \sin(nk\omega\Delta t) \\
 &\quad + w_{2n} \cos(nk\omega\Delta t)] \\
 &= i_{L,f,p}(k) + i_{L,f,q}(k) + i_{L,h}(k) \\
 \bar{i}_L(k) &= \bar{W}^T \bar{X}(k)
 \end{aligned}$$

Where, The weight matrix $\bar{W}^T = [w_{11} w_{21} \dots w_{1N} w_{2N}]$

$$\text{Sin/cos } \bar{X}(k) = \begin{bmatrix} \sin(k\omega\Delta t) \\ \cos(k\omega\Delta t) \\ \vdots \\ \sin(Nk\omega\Delta t) \\ \cos(Nk\omega\Delta t) \end{bmatrix}$$

To access the currents, we need a correct estimate of (k). For this purpose, an adaptive ANN algorithm was used for training.

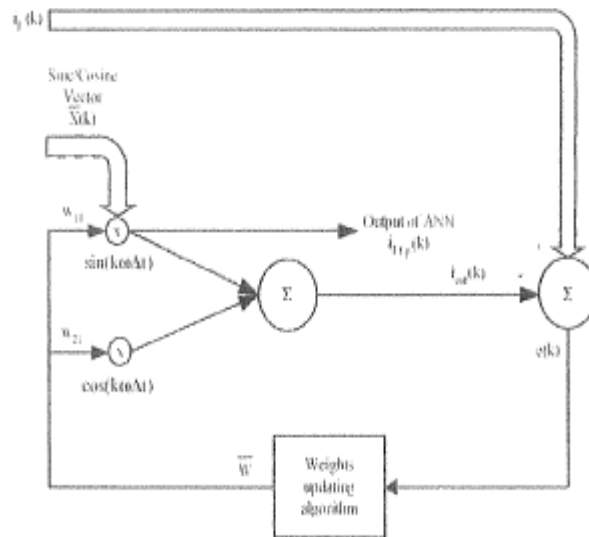


Fig. 2. An adaptive ANN extraction circuit with a modified W-H algorithm

The most important component of a block extraction circuit is to update the weights. The modified W-H algorithm with the following Equation was used in this study:

$$\bar{W}(k+1) = \bar{W}(k) + \frac{\gamma e(k)\bar{X}(k)}{X^T(k)\bar{X}(k)}$$

And this is the learning rate:

$$\gamma \text{ \& } \bar{X}(k) = \begin{bmatrix} \sin(k\omega\Delta t) \\ \cos(k\omega\Delta t) \end{bmatrix} \text{ \& } \bar{W}^T = [w_{11} w_{21}]$$

This method is based on minimizing the Mean Squared Error (MSE) between the actual measured signal (k) and the estimated signal $\hat{i}_{cs}(k)$. The modified W-H algorithm updates only two weights of the principal component at the same time. Thus, the number of updated weights is not a function of the harmonic order N (in the W-H method). The correction performed in the W-H algorithm is based on the orthogonality of x(k) elements. With this correction, the repetition rate can be increased significantly, which increases the rate of signal estimation. The disadvantage of this method is the relatively higher error e(k), which can be controlled by choosing a suitable learning rate between 0 and 1/N. In each repetition, the signal of the error e(k) is used in

Equation 3 to calculate the weights of the next repetition $\bar{W}(k+1)$ so that e(k) is minimized. After the process is done, several repetitions (k) will converge and coincide with (ik). The initial value of the weights is also randomly selected.

Self-Charging circuit

As mentioned, the dynamic behavior of the active filter directly depends on the return of the capacitor to its reference value. Thus, a circuit is needed to calculate the amount of active power required by DC capacitors. Then, by calculating the capacitor charging currents and applying them to the source, it forces the source to inject active power into the active shunt filter.

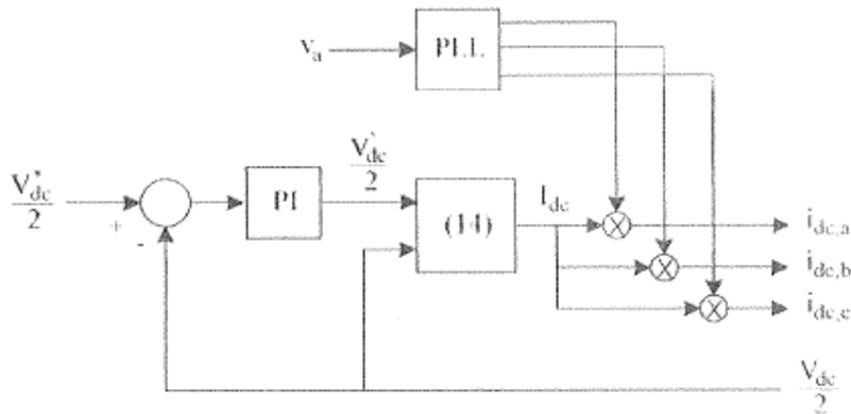


Fig. (3-7). Self-charging circuit with PI controller

The energy E stored in each capacitor is as follows:

$$E = 1/2C(V_{dc}/2)^2$$

Where,

C : The capacity of each capacitor

$V_a/2$: The voltage of each capacitor

When the capacitor voltage changes from $V_{dc}/2$ to $\frac{V_{dc}}{2}$ during the charging process, the new energy of each capacitor, E' , is as follows:

$$E' = 1/2C(\hat{V}_{dc}/2)^2$$

The difference between E and E' is as follows:

$$\Delta E = \hat{E} - E = 1/2C\left[\left(\frac{\hat{V}_{dc}}{2}\right)^2 - (V_{dc}/2)^2\right]$$

On the other hand, the charging energy of the capacitor, E_{as} , which is delivered to the inverter by the three-phase source, is as follows:

$$E_{as} = 3Pt = 3(V_{ms}I_{ds,ms} \cos\phi)l$$

Where V_{rms} is the rms value of the source instantaneous voltage, I_{drms} is the rms value of the instantaneous capacitor charging current, and ϕ is the phase difference between the source voltage and the capacitor charging current until the charging process of each capacitor is completed in a half cycle. The value of $T/2$ is defined, where T is the period of the source frequency. V_{ms} and $I_{ds,ms}$ can be expressed in terms of their peaks, V , and I values. By phase matching the source voltage V with i_{dc} using the PLL block, the power factor ($\cos Q$) will be equal to "1". According to the above, Equation 7 will be obtained as following Equation:

$$E_{as} = 3 \frac{V I_{ds} T}{\sqrt{2} \sqrt{2} 2}$$

If we ignore the switching losses, the IDC can be obtained from the following Equation:

$$\Delta E = E_{as} = \frac{1}{2C} \left[\left(\frac{\hat{V}_{dc}}{2} \right)^2 - (V_{dc}/2)^2 \right] = \frac{3VI_{ds}T}{4}$$

$$I_{ds} = \frac{2C \left[\left(\frac{\hat{V}_{dc}}{2} \right)^2 - (V_{dc}/2)^2 \right]}{3VT}$$

Thus, by receiving the value of $V_{DC}/2$ and $V_{DC}^*/2$, the PI controller calculates the value of $V_{DC}/2$ for use in Equation 9. The PI can also eliminate the steady-state offset between the reference value of $V_{DC}^*/2$ and the actual value of $V_{DC}/2$. So far, the peak charge current of the capacitor has been calculated. But to determine the I_{DC} value, the charging current phase must be known. Hence, we use the PLL block. The PLL aligns itself with the supply voltage of phase "a", v_a , and produces three Sin waves with a phase difference of 120° . I_{dc} and i_{dc} of the three phases are obtained by multiplying these three waves by the peak value of the charging current. After this step, the power supply must be forced to inject i_{dc} current into the filter. For this purpose, we add i_{dc} to the injection currents i_{inj} .

$$i_{inj,a} = i_{Lfq,a} + i_{Lhg,a} - I_{dc} \sin(\omega t)$$

$$i_{inj,b} = i_{Lfq,b} + i_{Lhg,b} - I_{dc} \sin(\omega t - 120)$$

$$i_{inj,c} = i_{Lfq,c} + i_{Lhg,c} - I_{dc} \sin(\omega t + 120)$$

By entering a negative sign in the third term, the current i_{dc} is guaranteed towards VSI. Hence, we right now have achieved the mathematical expression of i_{inj} . But to realize that, we need a hysteresis control that can deliver I_{inj} in output VSI with switching control in VSI.

Hysteresis control and injection circuit

The hysteresis control requires two inputs to realize i_{inj} in the VSI output. They are as follows:

(I) i_{inj} , which is considered as the reference signal. It is expressed by Equation 10.

(II) Injection current i_{inj} which is measured at the VSI output and applied as feedback to the hysteresis controller. Hysteresis control uses the difference

between these two values with the following Equation to control the IGBTs of VSI.

$$\Delta i_{ing} = i_{ng}^* - i_{ng}$$

Currently, the following Equation shows how the switches are turned on and off.

$$Sw = hys(\Delta i_{inf}) = \begin{cases} 1 & \text{if } \Delta i_{inf} > b \\ 0 & \text{if } \Delta i_{inf} < -b \end{cases}$$

Where,

b: hysteresis band

Sw: IGBT state

The injection circuit also includes a first-order low-pass filter that is connected to the VSI output. The design of this filter is based on the following Equation:

$$\frac{i_{ng}}{(V_{dc}u/2) - v} = \frac{1}{sL_{lh}}$$

The final model

Currently, the final model includes i. Adaptive ANN extraction circuit, ii. Self-charging circuit, iii. Hysteresis control, and iv. Injection circuit that is integrated as below:

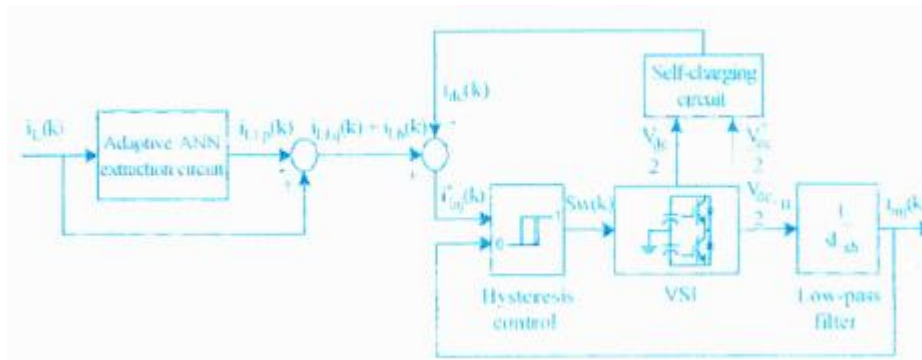


Fig. 4. The final model of the adaptive shunt active filter

The nonlinear load current was sampled by $I_1(K)$. Then, $I_1(K)$ is given to the adaptive ANN extraction circuit to generate $i_{Lh}(k)$ & $i_{LF,q}(k)$. These two currents with the current $i_{dc}(k)$ obtained from the self-charging circuit generate the reference injection current i_{inj} for hysteresis control. At injection current measured at the VSI output, i_{inj} is also given to the hysteresis so that the IGBT gates turn on and off according to Equation 12 until i_{inj} approaches i_{inj} .

Simulation of adaptive shunt active filter with ANN controller

Now, we consider again the same load with a random variation. As before, first, we check the dynamic mode behavior of the filter by examining the DC capacitor. The neural network method used in this simulation was a 3-layer ADALINE network, in which the first layer had one input neuron, the middle layer had four neurons, and the third layer had eight neurons. The result of updating the weights for one repetition is given below:

Table 1.

The first layer	
0.76551678149002	
0.795199901137063	

Table 2.

The middle layer	
0.186872604554379	0.709364830858073
0.48976439578231	0.754686687982361
0.4455862007109	0.276025076998578
0.646313010111265	0.679702676853675

Table 3.

The third layer			
0.655098003973841	0.751267059305653	0.149294005559057	0.196595250431208
0.162611735194631	0.255095115459569	0.257508254123736	0.251082857976031

0.118997681558377	0.505957051665142	0.840717255983662	0.616044676146639
0.498364051982143	0.69076722656686	0.254282178971531	0.47328848902729
0.959743958516081	0.890903252535798	0.814284826068816	0.351659507062997
0.340385726666133	0.959291425205444	0.243524968724989	0.830828627896291
0.585267750979777	0.547215529963803	0.929263623187228	0.585264091152724
0.22381939491137	0.138624442828679	0.349983765984809	0.54972360829114

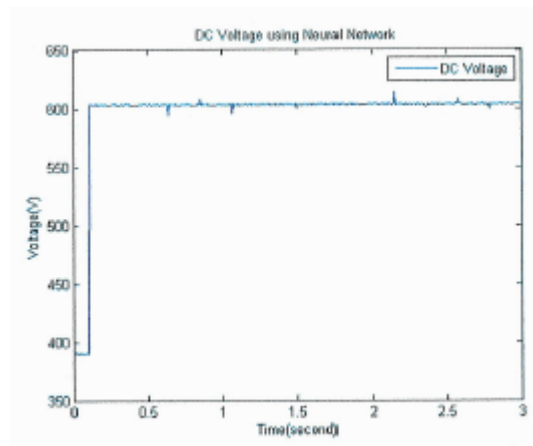


Fig. 5. DC voltage of the capacitor

As can be observed, the voltage remains in the range of 600 V at all moments of load change. To study the

steady-state behavior of the filter, the THD diagram was obtained as follows:

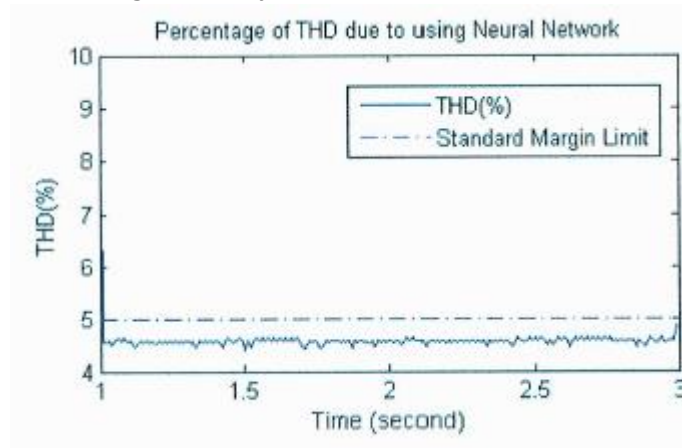


Fig. 6. The THD percentage

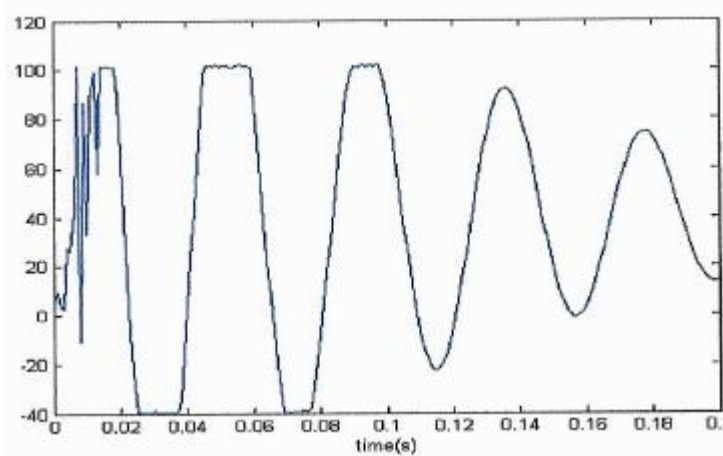


Fig. 7. Load current in phase "a"

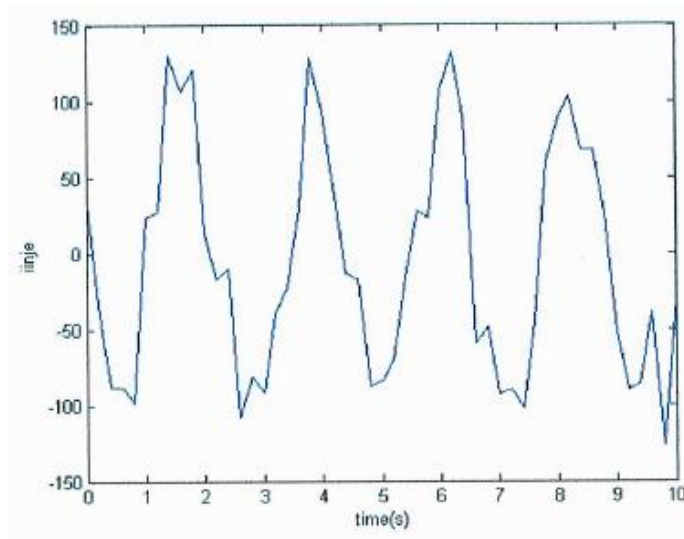


Fig. 8. Current injected into phase "a" by the filter

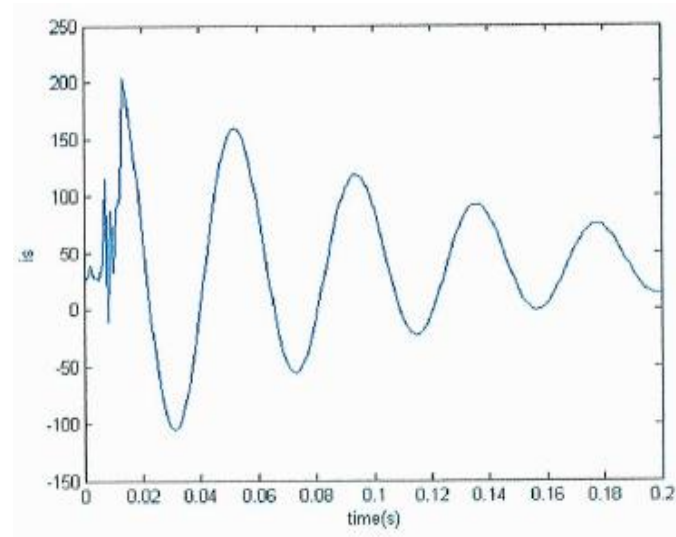


Fig. 9. Source current in phase "a"

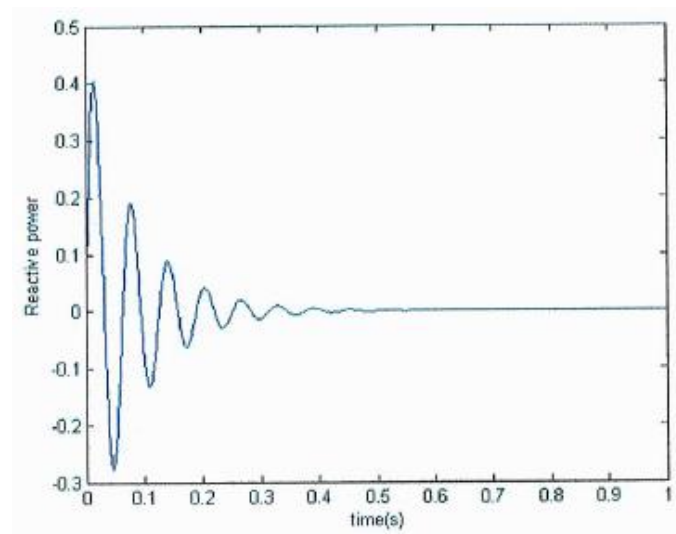


Fig. 10. Reactive power received from the source

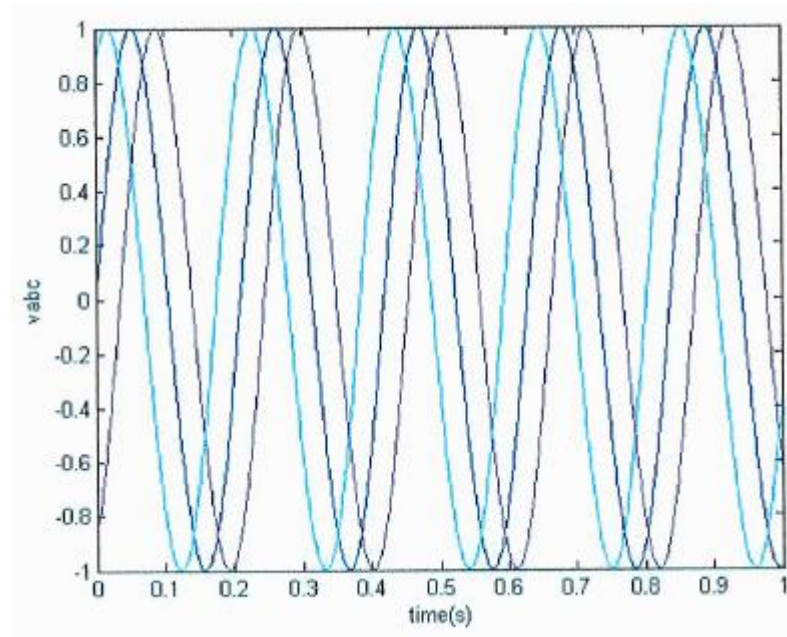


Fig. 11. Voltage profile at PCC point

Conclusions

Based on simulation results, the reactive power received from the source reaches “0” after one cycle. The result included a power factor of “1” and an ideal performance of the adaptive shunt active filter for load changes. Also, the dynamic performance of the filter was ideally improved. The THD (%) of the source current during the load changes was always less than five, indicating the ideal performance of the adaptive shunt active filter in the steady state. To continue this research and improve the power quality by active filters, the following are suggested: (I) Using a feedforward neural network instead of a hysteresis controller to improve the regulation of switching signals, (II) Making corrections in the modified W-H algorithm to reduce the algorithm error, and (III) Using ADALINE neural network for PI and a fuzzy controller instead of neural hysteresis controller.

References

1. Johan Lundquist, on Harmonic Distortion in Power Systems, Thesis for the degree of licentiate of Engineering, Department of Electric Power Engineering Chalmers University of Technology, Gothenburg, Sweden, 2003
2. L.H.Tey, & Y.C.Chu, Improvement of power quality using adaptive shunt active filter, IEEE Trans, Power Delivery, APRIL 2005, Vol.20, No.2, pp.1558-1568
3. E.L.Owen, A History of Harmonics in Power Systems, IEEE Industry Application Magazine, Feb. 1988, pp 6-12
4. J. Arrillaga, D.A.Bradley and P.S.Bodger, Power System Harmonics, Book, John WILEY & Sons, UK, 1985
5. F.Z.Peng and D.J Adams, Harmonic Sources and Filtering Approaches, IEEE Industry Applications Magazine, Vol. 1, Issue 4, Jul./Aug. 2001
6. F.Z.Peng, Application Issues and Characteristics of Active Power Filters, IEEE/IAS Magazine, Sep./Oct. 1998
7. IEEE Std 519-1992, IEEE Recommended Practice and Requirements for Harmonic Control in Electrical Power System