

Unified Power Quality Conditioner Based on Neural-Network Controller for Mitigation of Voltage and Current Source Harmonics

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Abstract – Unified Power Quality Conditioner (UPQC) consists of series and shunt active filter sharing a common dc bus capacitor. The series active filter minimizes voltage source harmonics. The shunt active filter is designed to decrease harmonic current-components generated by the nonlinear loads. Thus with compensating effectively all harmonics and reactive power improves power factor. For optimal mitigation of voltage/current source harmonics, a neural network is proposed to control the UPQC. The artificial neural network (ANN) controller has been designed to extract fundamental frequency components from non-sinusoidal. Three multilayer perceptron neural networks are used to identify and reduce the harmonics. A back-propagation algorithm trains this network. Simulation carried out by Matlab/Simulink and results verify the efficiency of the proposed UPQC.

Keywords: Harmonic compensation, Instantaneous active and reactive power theory, Unified Power Quality Conditioner (UPQC), Power quality, Neural network

1. Introduction

Power Quality is an important concern for the Industry nowadays. Harmonics produced by nonlinear loads, such as rectifiers, arc furnaces, power electronics converters, controllers for variable-speed motor drives, electronic power supplies, DC motor drives, battery chargers, and electronic ballasts can create high disturbances and problems in the power quality [1], [2].

Harmonic distortion in power distribution systems can be minimized using two approaches namely, passive and active power filters. The passive filtering is the simplest conventional solution to suppress the harmonic distortions. Although simple and least expensive, the passive filter has several barriers. The filter components have large size, depends on the source impedance, resonance problem, thus it affects on the stability of the power distribution systems [3].

Presently, active power filters (APFs) are becoming more affordable due to cost reductions in power semiconductor devices, their auxiliary parts, and integrated digital control circuits. In addition, the APF also acts as a power-conditioning device which provides a cluster of multiple functions, such as harmonic filtering, damping, isolation and termination, load balancing, reactive-power control for power factor correction and voltage regulation, voltage flicker reduction and their combinations. Recent research presents applications of the unified power quality

conditioner (UPQC) to compensate the power quality problems [4- 9].

In active power filter (APF) design and control, calculation of compensation voltage/current and reference signal generation is important task. Filtering characteristics strongly depend on the accuracy of reference signal and its speed of computation. The several schemes have been developed and studied for the control of active filters such as Fast Fourier Transform (FFT), Kalman filter and artificial neural network (ANN) [10].

Artificial intelligence is an important area and it has ability to handle complex problems. Neural network is an important tool of this category, which can be trained for a specific task such as signal extraction or pattern reorganization, etc. Nowadays, these tools are used for improving of the power quality problems effectively and produce good performance even under distorted supply voltage conditions by suitable training [11], [12].

In this paper, a three phase- three wires UPQC controlled by neural network method is proposed. The proposed controller requires a low processing time, and allows a fast calculation of the reference voltages/currents and it is simple in architecture. It can be successfully applied for harmonic filtering under various power system operating conditions. The proposed controller has been investigated under different non-sinusoidal for its performance.

2. System Configuration

The UPQC is the integration of shunt and series APFs through a common DC link capacitor. Fig.1 shows the scheme of installed UPQC in distribution system which is including nonlinear loads. The load may be either single phase, two-phase or three-phase may be balanced or

unbalanced connected to the supply mains via a bridge rectifier which define load nonlinearity. The series active filter was designed to compensate harmonic currents produced by nonlinear loads. The shunt active filter consists of a three-phase voltage source converter (VSC) connected in parallel with the power grid.

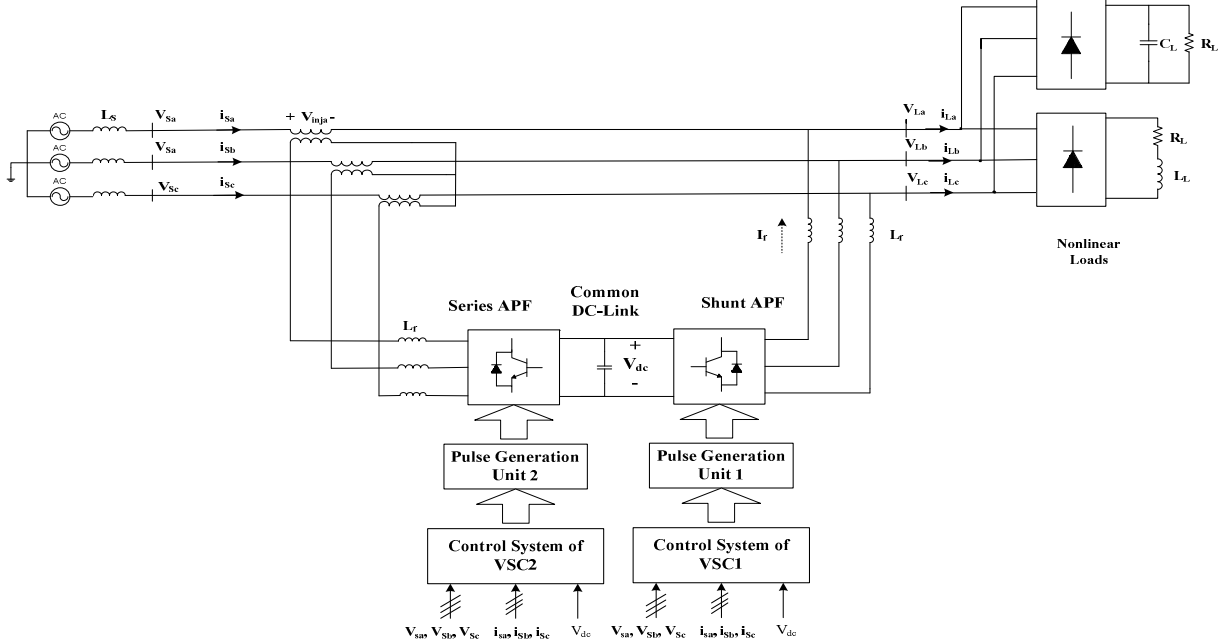


Fig. 1. The scheme of installed UPQC in distribution system

3. Operation Principle of Unified Power Quality Conditioner

The equivalent circuit of the UPQC in form of single-line is shown in Fig.2. The main voltage is modeled as voltage source V_s in series with an impedance Z_s . The source harmonic voltage is V_{sh} . The current type nonlinear load is modeled by a harmonic current source I_{LHV} while the voltage source non-linear load is modeled by its equivalent Thevenin circuit, V_{LHV} , in series with Z_{Lh} . The series active filter acts as a damping resistance, which can damp the parallel resonance between the shunt passive filter and the source impedance, and acts as harmonic voltage source blocking resistance. The impedance of the shunt passive filter Z_f is in shunt with the loads.

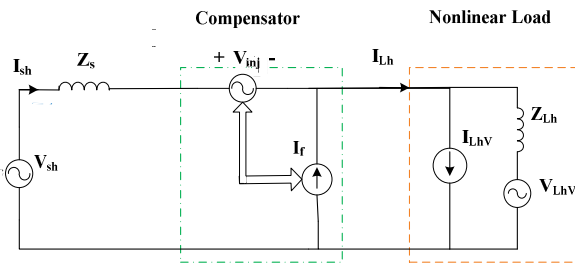


Fig. 2. Equivalent circuit at harmonic frequencies

The harmonics flowing in the source, which is produced by both load harmonics I_{LHV} and source harmonic I_{sh} .

The series active filter acts as series synchronous voltage in the line. The shunt active filter acts as current source and compensates the current harmonics.

4. Instantaneous Power Theory based Control Strategy

The basic p-q theory control algorithm block diagram is shown in Fig.3. From the equation of (1) and (2), the basic p-q theory consists of an algebraic transformation of the measured source voltage (V_{Sa}, V_{Sb}, V_{Sc}) and source current (i_{Sa}, i_{Sb}, i_{Sc}) in the a, b, c coordinates to α, β coordinates, followed by the calculation of the instantaneous power components (p, q) [13- 15].

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \quad (1)$$

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

Instantaneous real power (p) and reactive power (q) are calculated according of equation (3).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V_\alpha & V_\beta \\ -V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (3)$$

The instantaneous real and reactive powers can be expressed as follows:

$$\begin{aligned} p &= \bar{p} + \tilde{p} \\ q &= \bar{q} + \tilde{q} \end{aligned} \quad (4)$$

Where \bar{p} is the dc component (average power) of the instantaneous power p , \tilde{p} is the ac component of the instantaneous power p , and is related to the harmonics, \bar{q} is the dc component of the reactive instantaneous power q , \tilde{q} is the ac component of the instantaneous reactive power q , and is related to the harmonics.

In order to compensate reactive power and current harmonics generated by nonlinear loads, the reference signal of the shunt active power filter must consist the values of \tilde{p} , \tilde{q} . The storage capacity C absorbs the power fluctuations caused by the compensation of the reactive power, the average voltage across the capacitor terminals must be regulated at a constant value. The regulation of this voltage is made by absorbing or providing active power (p_{loss}) on the electrical network. The correction of this voltage must be done by adding the fundamental

active voltage in the reference voltage of APF (\tilde{p} is changed to $\tilde{p} + p_{loss}$). In this case, the reference voltages required by the shunt APF are calculated with the following expression:

$$\begin{bmatrix} i_{Ca}^* \\ i_{Cb}^* \\ i_{Cc}^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} V_\alpha & -V_\beta \\ V_\beta & V_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} + p_{loss} \\ \tilde{q} \end{bmatrix} \quad (5)$$

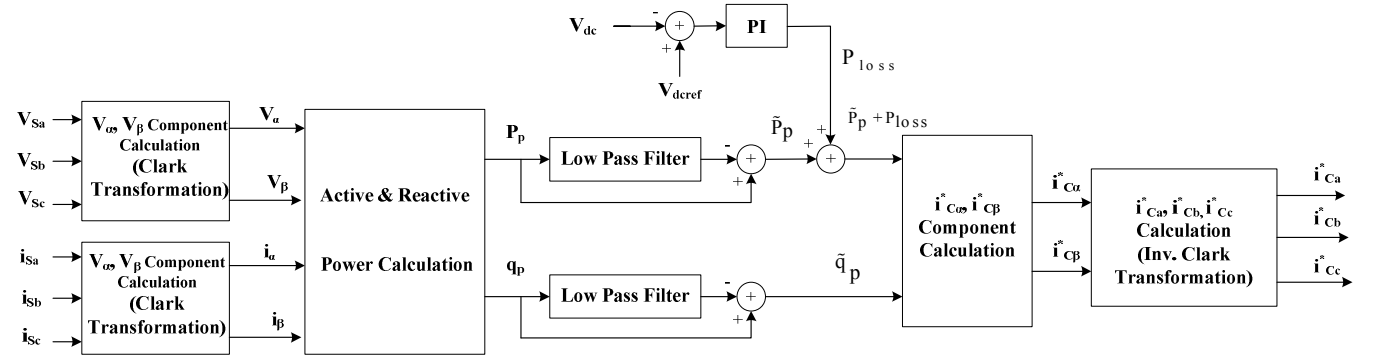
The final compensating currents components in a, b, c reference frame are the following:

$$\begin{bmatrix} i_{Ca}^* \\ i_{Cb}^* \\ i_{Cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Ca}^* \\ i_{Cb}^* \end{bmatrix} \quad (6)$$

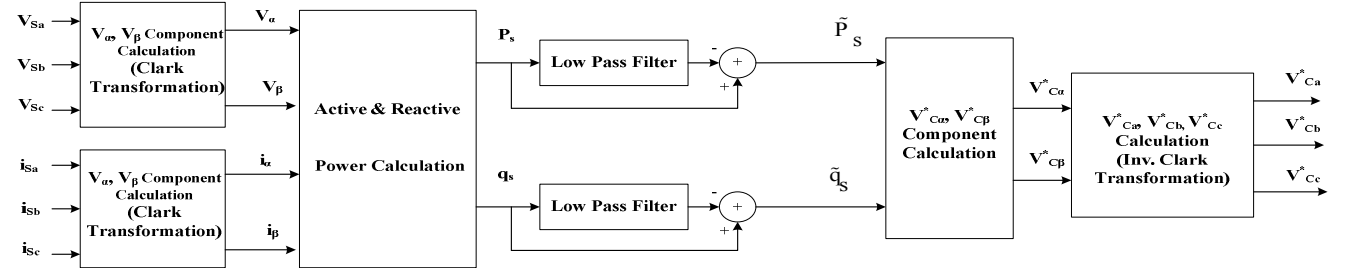
Also, the final compensating voltages components in a, b, c reference frame for control system of series APF are the following:

$$\begin{bmatrix} V_{Ca}^* \\ V_{Cb}^* \end{bmatrix} = \frac{1}{i_\alpha^2 + i_\beta^2} \begin{bmatrix} i_\alpha & -i_\beta \\ i_\beta & i_\alpha \end{bmatrix} \begin{bmatrix} \tilde{p} \\ \tilde{q} \end{bmatrix} \quad (7)$$

$$\begin{bmatrix} V_{Ca}^* \\ V_{Cb}^* \\ V_{Cc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} V_{Ca}^* \\ V_{Cb}^* \end{bmatrix} \quad (8)$$



a)



b)

Fig. 3. Block diagram of control system based on the instantaneous active and reactive power for UPQC, a) shunt APF, b) series APF

5. Neural Network for Estimation of Reference Injected Voltage/Currents by Unified APF

A. The Architecture of ANN

In this work, the p-q theory method based control system depicted in Fig.4 modeled and replaced by an artificial

neural network (ANN) made up of two hidden layers with 21 neurons each, and one output layer with 3 neurons. The ANN for control system of shunt APF has seven inputs ($V_{Sa}, V_{Sb}, V_{Sc}, i_{Sa}, i_{Sb}, i_{Sc}$ and V_{dc}) and three outputs ($i_{Ca}^*, i_{Cb}^*, i_{Cc}^*$) as observed in the p-q theory.

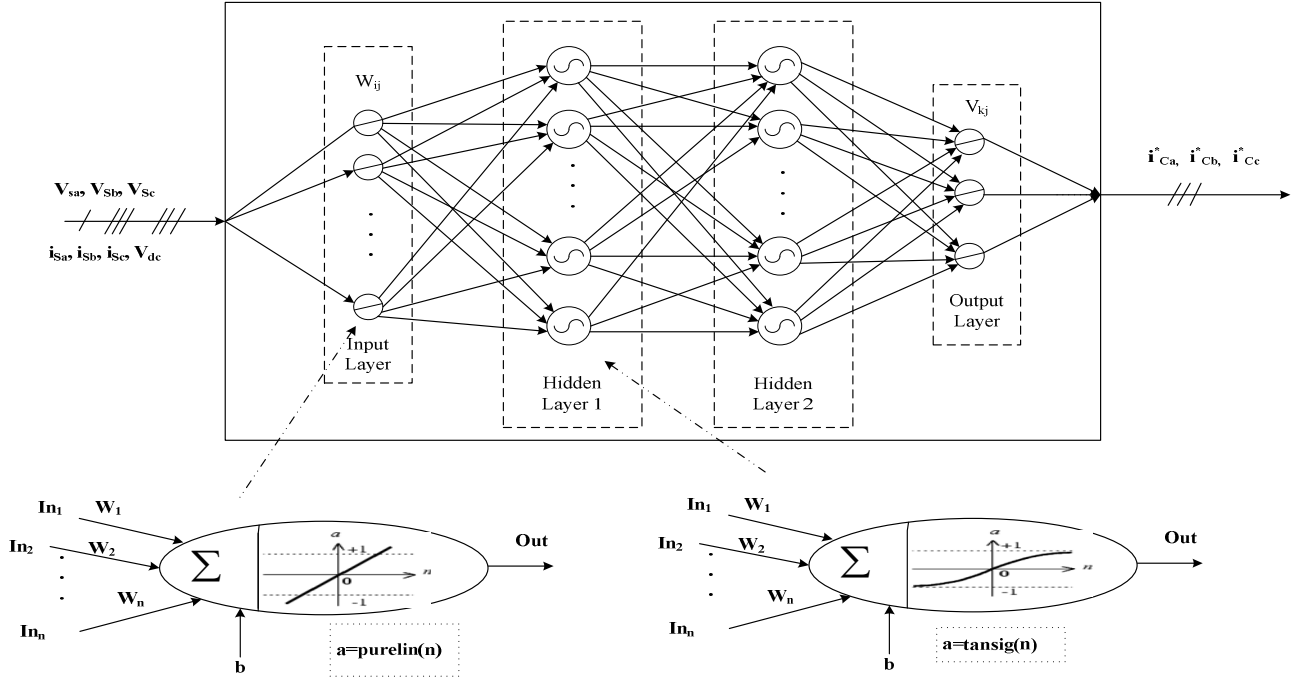


Fig. 4. Neural network for estimation of reference injected current

Also, the ANN for control system of series APF has seven inputs $V_{Sa}, V_{Sb}, V_{Sc}, i_{Sa}, i_{Sb}, i_{Sc}$ and three outputs ($V_{Ca}^*, V_{Cb}^*, V_{Cc}^*$) as observed in the p-q theory.

B. The Procedure of Training ANN

The ANN is trained by varying the weights W_{ij} and the biases B_j . The training criterion is taken as the mean square error of the ANN output with a value of 0.0001 and the error function is defined to following equation:

$$J = \sum_{i=1}^N e(i)^2 \quad (9)$$

Where N is the number of output neurons and $e(i)$ is the instantaneous error between the actual and estimated values of the output. The training is completed when the value of J is less than 0.0001 [16].

Before starting training, weights are started with small random values to reduce the chance of prematurely saturating the logistical neurons and thus reducing the training speed. The common principle of second order algorithms is to compute a descent direction obtained by a linear transformation of the cost function gradient. For the gradient algorithm, the weights are updated at each step according to:

$$W(t+1) = W(t) + \Delta W \quad (10)$$

$$\Delta W_{ij} = -\eta \frac{\partial J}{\partial W_{ij}} \quad (11)$$

Where η is the learning rate parameter. A large learning rate might lead to oscillations in the convergence trajectory,

while a small learning rate produces a smooth trajectory at the cost of slow convergence speed [17].

6. Simulation Results

The performance of the proposed detection method using ANN based UPQC has been simulated in Matlab/Simulink environment.

Fig.5 shows the training, validation and test errors to check the progress of training. This result is reasonable, since the test set error and the validation set error have similar characteristics, and it doesn't appear that any significant over fitting has occurred.

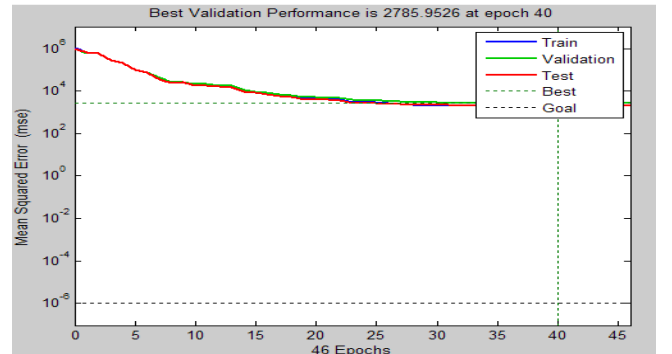


Fig.5 Training validation and test curves of neural network

The following figure shows the graphical output provided by postreg. The network outputs are plotted versus the targets as open circles. The best linear fit is indicated by a dashed line. The perfect fit (output equal to targets) is

shown by the solid line. Output seem to track the targets reasonably with regression of 0.78.

The simulation results of the system for load voltage (V_{Load}), injected voltage (V_C) by active filter, voltage of DC- Link capacitor (V_{dc}) source voltage (V_{source}) are shown in Fig.6. The harmonics of the voltage has been reduced after compensation.

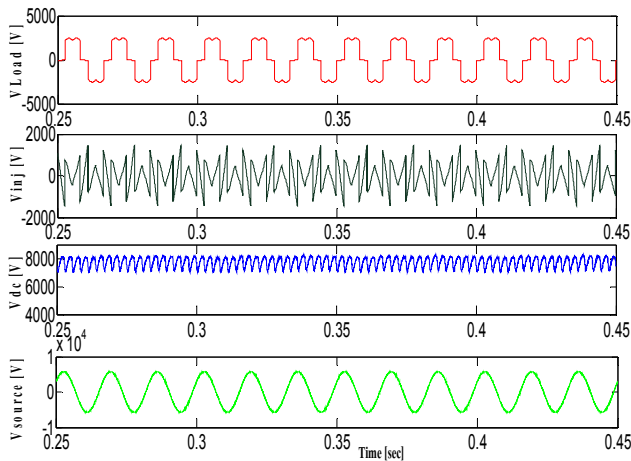


Fig. 6. (a) single- phase of the simulated- load voltage waveform, (b) injected voltage waveform by series active power filter, (c) dc- link capacitor voltage, (d) the source voltage waveform

Fig.7 shows the load current (I_{Load}), injected current (I_{sh}) by shunt active filter, source current (I_{source}). The harmonics of the current has been suppressed after compensation.

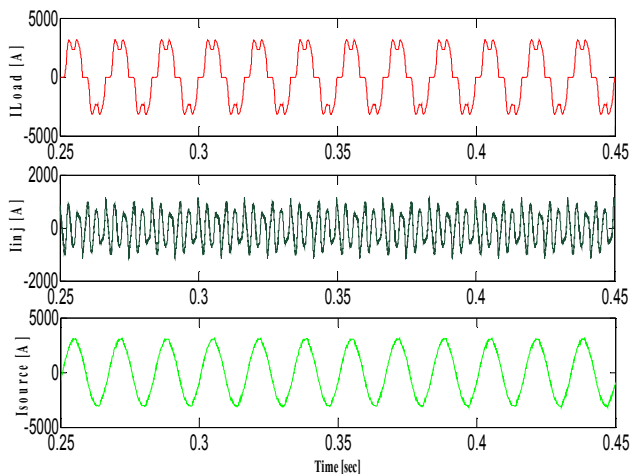


Fig. 7. (a) single- phase of the simulated- load current waveform, (b) injected current waveform by shunt active power filter, (c) the source current waveform

Fig. 8 compares harmonic spectrum of source voltage in neural network method and p- q theory method. THD levels of source voltage reduced from 21.65% to 1.08% which

shows the performance of proposed controller (neural network).

THD of control system based on neural network is less than control system based on p- q theory method.

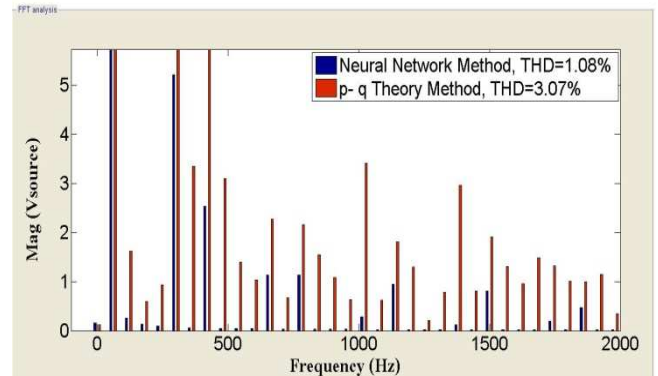


Fig. 8. Comparison between harmonic spectrum of source voltage Phase 'a' in neural network method and p- q theory method

Fig. 9 shows comparison between harmonic spectrum of source current in neural network method and p- q theory method. THD of control system based on neural network is reduced significantly.

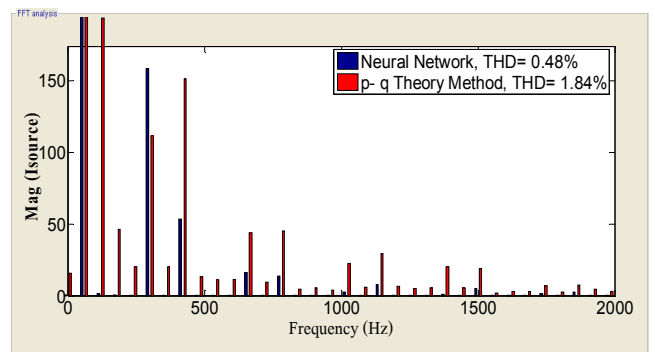


Fig .9. Comparison between harmonic spectrum of source current Phase 'a' in neural network method and p- q theory method

6. Conclusion

This paper presents the novel control strategy based on intelligent neural techniques in unified APF. The proposed UPQC is able to improve the power quality in grid side and suppress harmonics caused by nonlinear loads. The artificial neural network is applied to extract the harmonic component of the load voltage/current to produce reference voltage/current; (p-q theory) have been accomplished. The total harmonic distortion with UPQC based on neural network is less than UPQC based on p-q theory method.

Appendix

Table I indicates the applied parameters in simulation.

TABLE I

THE APPLIED PARAMETER IN SIMULATION

Parameter	Value
Line voltage, frequency	4160V, 60Hz
Line impedance	$L_s=0.01\text{mH}$, $R_s=0.1$
Current-source type of nonlinear load impedance	$L_l=30\text{mH}$, $R_l=12$
Voltage-source type of nonlinear load impedance	$C_l=400\mu\text{H}$, $R_l=24 \Omega$
Series active filter parameter	$L_f=3.3\text{mH}$, $C_f=5\mu\text{F}$, $R_f=5\Omega$, $C_{dc}=1000\mu\text{F}$

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