NEW CONTROL SCHEME OF ACTIVE FILTER BASED ON NARX NETWORK

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Abstract: *This paper presents a novel shunt active power filter control reference signal using nonlinear autoregressive with exogenous neural network (NARX) with back propagation training algorithm. The instantaneous reactive power algorithm is integrated within the neural network to extract the dominant harmonics. The static back-propagation learning algorithm is applied to train the proposed series parallel NARX network to identify the load model. Then the training process will be tested for the load after changing the architecture of the NARX network from series-parallel to parallel by applying the actual measured voltage. The proposed method is demonstrated on three phase thyristor controlled drive which is one of widely used loads in petroleum industry field.*
Key words: *NARX neural network; nonlinear loads; shunt active power filter; instantaneous reactive power algorithm.*

1. Introduction

The rapid increase in electronic device technology cause industrial loads to become nonlinear and consequently results in significant level of harmonic distortion. Harmonic current drawn from the supply by the nonlinear loads results in the distortion of the supply voltage waveform at the point of common coupling (PCC) due to the source impedance. Harmonics generally are affected badly on utility and customer equipments. They may cause protection devices malfunction, increase power losses and line temperature and create noise and resonance [1].

Active power filter (APF) provides a solution of the problems of power quality such as reactive power compensation, harmonic mitigation and harmonic damping [2]. According to their topology, active filters can be divided to shunt, series and unified or hybrid active power filters. Shunt active power filter is considered as the most popular topology of APFs [3-4]. The main purpose of shunt active power filters is to compensate harmonics of load current [5].

Series active power filter is more suitable for harmonic voltage sources loads, the main purpose of this type of active filters is to compensate negative sequence voltage and regulate voltage in three phase system [6].

Unified power quality conditioner is a combination of series and shunt active filters and its function is to isolate voltage and current harmonics. This type of active power filter is expensive and complex in control [7]. Hybrid active filter is raised up to reduce the initial cost of filtering, by using passive filter to tune up to the most dominant harmonic order and then connected with series or shunt active power filter. This will reduce active filter rating and cost in turn [8].

Many researchers interested in active power filters providing various types and classifications according to converter configuration, topology, application and control strategy. Ref. [10] proposed systems that achieve isolation at the dominant harmonic frequencies for six pulses rectifier from ends using square wave inverters. The artificial neural network technique was used for the control of active power filter [9, 11]. NARX is one of the Recurrent Neural Networks (RNN) schemes with global feedback. It considered as a time series forecasting networks [12]. It gives a dynamic responsibility, fast and accurate training response. NARX has a flexible architecture combining between simplicity (since it is simple to learn using backpropagation algorithms) and time series forecasting. The NARX is a perfect tool in simulating the complicated nonlinear systems because of its long term-dependencies and its computational power [13].

In this paper, shunt active power filter is proposed as a solution of harmonic distortion. The main issue for active power filter is to find a control method which quickly obtains the compensation reference current with minimal errors. The control has two steps; the first one is to generate the control reference signals and the second step carries out the control method [2].

The control reference signal of shunt active power filter is proposed using NARX neural network with backpropagation training algorithm. The instantaneous reactive power algorithm is integrated with the neural network to extract the dominant harmonics.

2. Instantaneous Reactive Power Algorithm

This method is also named the p–q method. It was introduced for active filter applications by Akagi. The current and voltage of the system are converted into the αβ0 system using the following equations [2]:

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

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

Based on p-q theory

$$p = v_0 i_0 + v_a i_a + v_b i_b \quad (3)$$

$$q = v_a i_a - v_b i_b \quad (4)$$

When the system is a symmetric three-phase or there is, no neutral point

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha v_\beta \\ -v_\beta v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \quad (5)$$

The active and reactive power in Eq. (5) can be decomposed into two parts: AC and DC parts. The DC part resulted from the fundamental current and voltage and the AC part resulted from the harmonics. The active and reactive power can be represented as:

$$p = \overline{p} + \tilde{p} \quad (6)$$

$$q = \overline{q} + \tilde{q} \quad (7)$$

$$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha v_\beta \\ -v_\beta v_\alpha \end{bmatrix} \begin{bmatrix} \overline{p} + \tilde{p} \\ q \end{bmatrix} \quad (8)$$

Where * denotes the reference value. These are reference values for the source currents. Therefore, the reference value for the active filter is as follows:

$$i_{\alpha AF}^* = i_\alpha^* - i_{L\alpha} \quad (9)$$

$$i_{\beta AF}^* = i_\beta^* - i_{L\beta} \quad (10)$$

The abc reference values for the active filter is

$$\begin{bmatrix} i_{aAF}^* \\ i_{bAF}^* \\ i_{cAF}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{\sqrt{2}} & \frac{\sqrt{3}}{2} \\ -\frac{1}{\sqrt{2}} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} \quad (11)$$

3. NARX Network Architecture

In this paper a series parallel architecture of NARX will be used. This form combines between the features of feed-forward network and dynamic networks, thus the input to the feed-forward network is more accurate and the static back-propagation can be used for training [14-16]. The static back-propagation learning algorithm is applied to train the series parallel NARX network to identify the load model.

The final architecture of NARX network is achieved through a training procedure. Two hidden layers will be used in our proposed NARX neural network but the entire neurons will be changed according to the type of each load and the complexity of its waveforms. The training process will be tested for each load after changing the architecture of the NARX network from series-parallel to parallel by applying the actual measured voltage.

The field measured and simulated data are used to build the corresponding NARX network using the PCC supply voltage and the corresponding load currents. Each network will be tested with pure sinusoidal voltage waveform and the resultant output will evaluate the true harmonics and nonlinearity of each load. The voltage waveforms will be used as a series-parallel NARX input, whereas the current waveforms will be used as the actual target, so that the training process can be applied faster and more accurate to each load.

The fast fourier transform (FFT) technique will be applied on the parallel NARX output and the results will be compared with the total harmonic distortion (THD) of actual measured current. If the THD of the parallel NARX output is the same as THD of the measured current, the training will be terminated as it gives a good result. The nonlinearity will appear for the load after making a good identification using parallel NARX architecture injected by generated pure voltage sinusoidal waveform. The output will be tested again with FFT and the estimated THD will indicate the actual load nonlinearity after removing the PCC effects. The designed architecture is illustrated in Fig. 1.

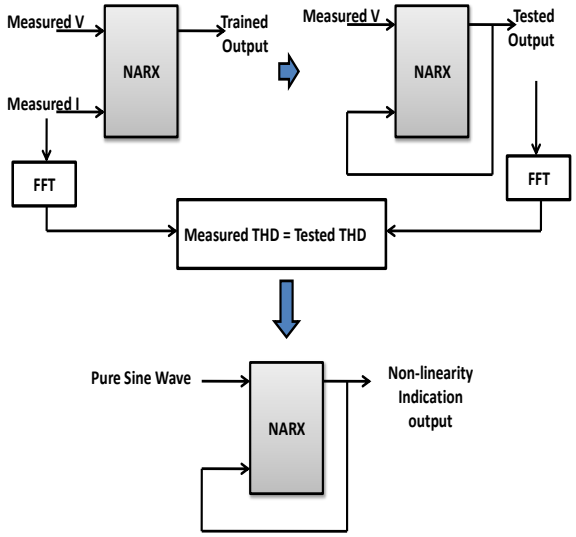


Fig. 1. NARX network architecture

4. NARX Control Reference Based Method for Shunt Active Power Filter

The NARX neural network based identifier is used to isolate the dominant harmonics from the rest of the current spectrum of a load. These isolated harmonics are then used with Instantaneous reactive power algorithm to mitigate the harmonics.

The PCC voltage and the non-linear load current are used to train the series parallel NARX network as the input and the target respectively. Then the NARX network will be converted to parallel NARX network so it will be injected with mathematically produced pure sinusoidal waveform.

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The NARX output waveform and the pure sinusoidal voltage waveform will be used in p-q method to produce the true harmonics of the nonlinear load.

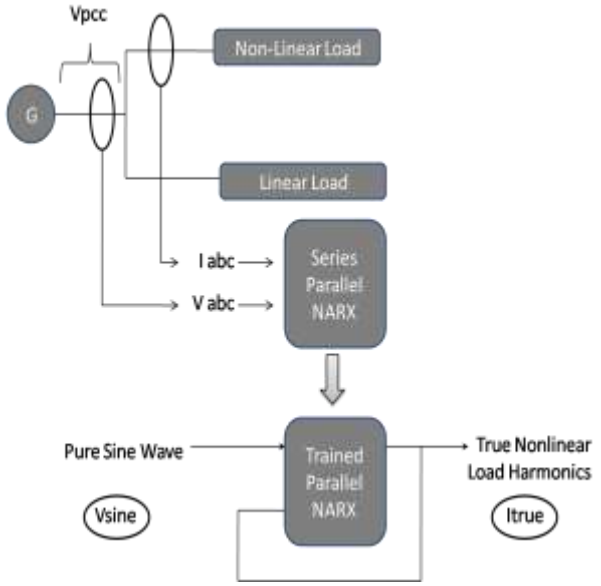


Fig. 2. The block diagram of NARX harmonics extraction

Fig. 2 shows the block diagram of NARX harmonics extraction and Fig. 3 shows the evaluation of instantaneous P and Q using the pure sine waveform (V_{sine}) and NARX output waveform (I_{true}).

The instantaneous P and Q are used to evaluate I_α , I_β which represent the final step before evaluating reference current as illustrated in Fig.4.

The references current are used to switch pulses to the power electronic elements GTO/Diodes to force the power converter to act as a current source to follow the reference current changes.

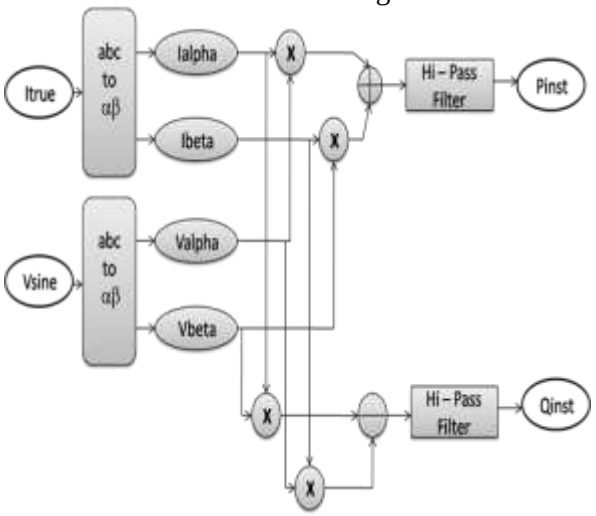


Fig. 3. Block diagram of evaluation of instantaneous P, Q using pure sine wave and corresponding NARX output

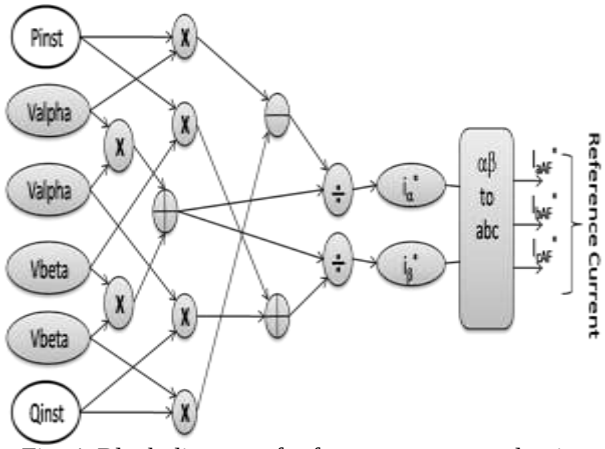


Fig. 4. Block diagram of reference current evaluation

5. Result and Discussion

The tested system consists of 50 Hz, 200 V, voltage source connected to nonlinear load 6-pusle converter system through(Y-Δ) transformer and 400 V dc, 5 Ω, 5.4 mH, 0.1μF active filter through 20 KVA (Y-Y) transformer. Fig. 5 illustrates the single line diagram of the tested system.

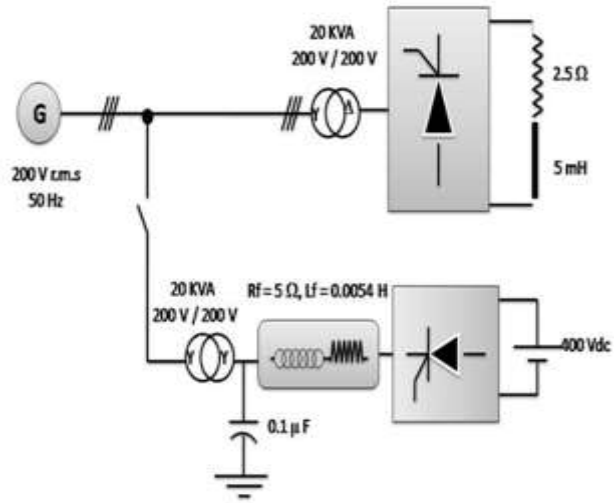


Fig. 5. Single line diagram of tested system

This case is applied using MATLAB/Simulink environments shown in Fig. 6. The purpose of this case is to study the harmonic extraction and controlled power electronic converter using PWM to mitigate a certain level of harmonic distortion using NARX. The nonlinear load current is shown in Fig.7.

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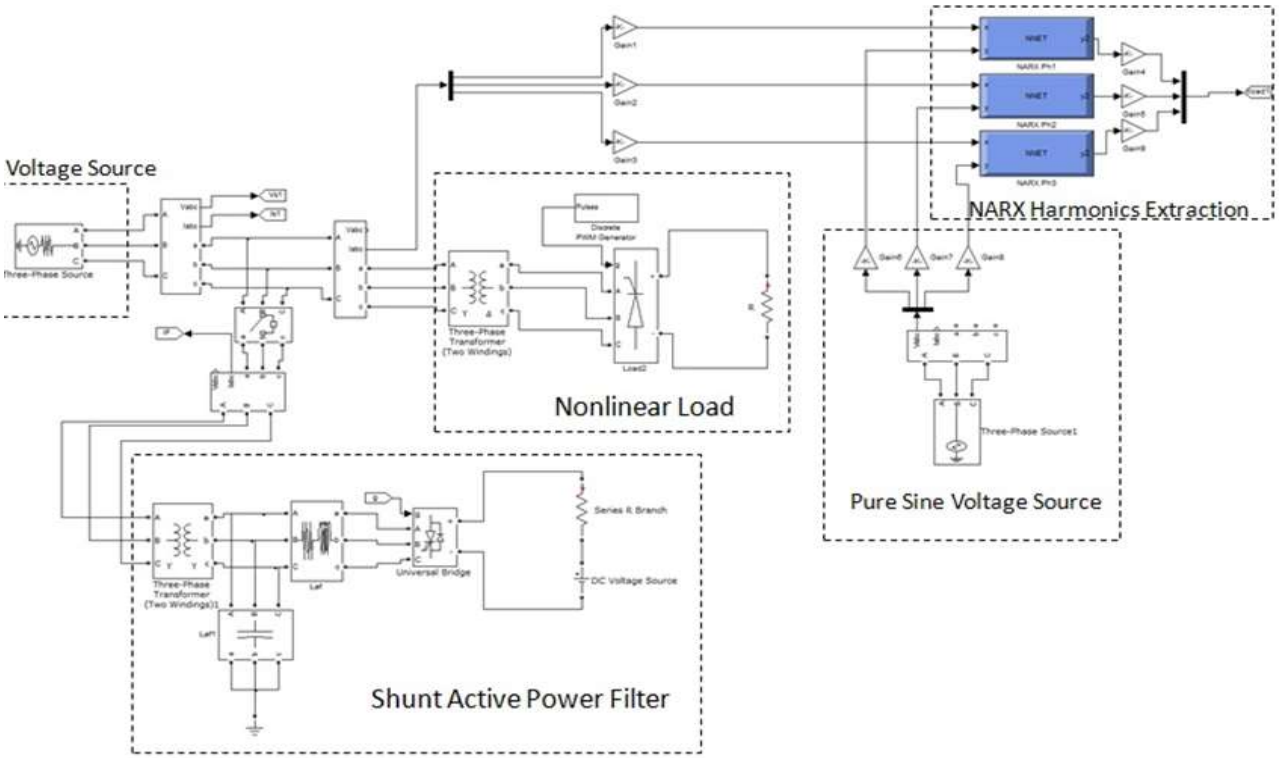


Fig. 6. MATLAB/Simulink model of the system

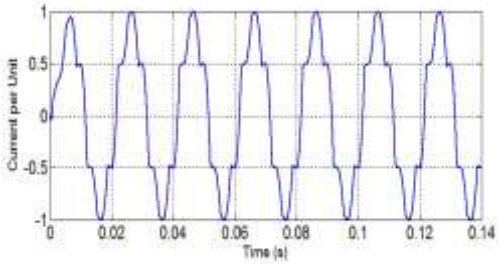


Fig.7. Nonlinear load current

Fig.8 illustrates the FFT analysis of the load current which shows that THD of 18.53%. The load voltage waveform and load current which are used to train the three NARX networks using 17 neurons in each hidden layers using 1005 samples per cycle; the training data for the three phases are summarized in the Fig. 9.

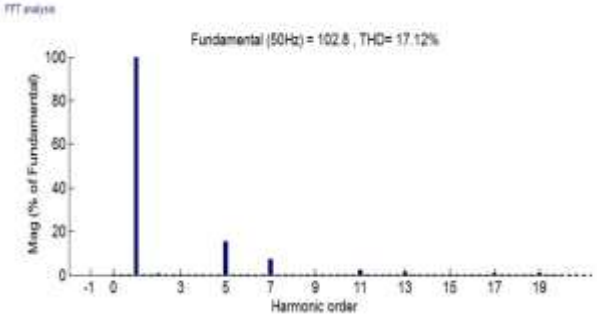
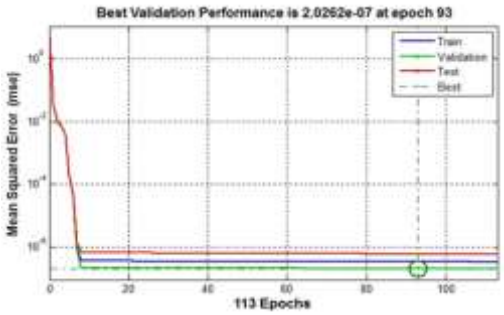
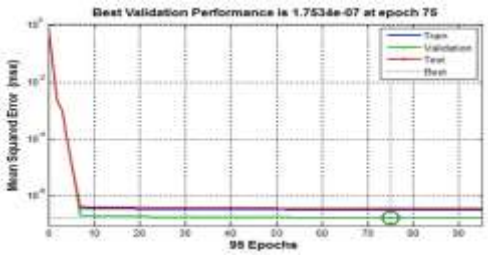


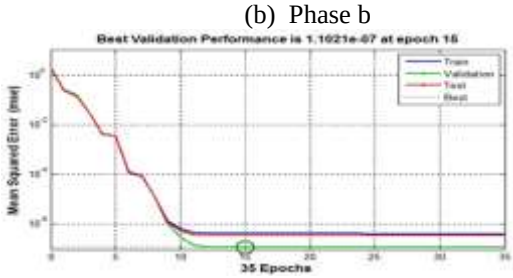
Fig. 8. FFT of nonlinear load current



(a) Phase a



(b) Phase b



(c) Phase c

Fig. 9. Training performance for the three phases

The training procedure is applied using backpropagation algorithm. The performance data illustrate the advantage of NARX series parallel network as the best validation achieved very fast and with mean square error less than 10^{-6}.

The fast performance of NARX series parallel network training procedure is suitable for the active power filter as it has a good response for the expected changes in waveforms. The comparison between the target waveform (nonlinear load current) and the NARX output using input voltage waveform is illustrated in Fig. 10.

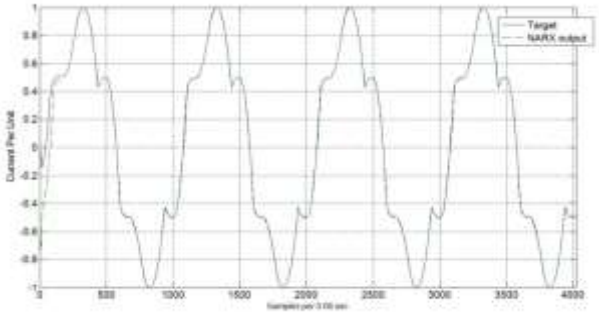


Fig. 10. Comparison between parallel NARX output and target waveforms

In the next step, the NARX network will inject by sinusoidal waveform which represent pure voltage source. The NARX output waveform and pure sinusoidal waveforms are used to evaluate the reference current using instantaneous reactive power technique as mentioned before. The instantaneous active and reactive power are illustrated in Figs. 11 and 12.

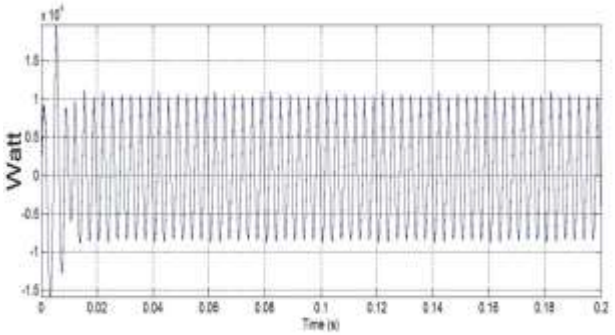


Fig. 11 Instantaneous active power waveform

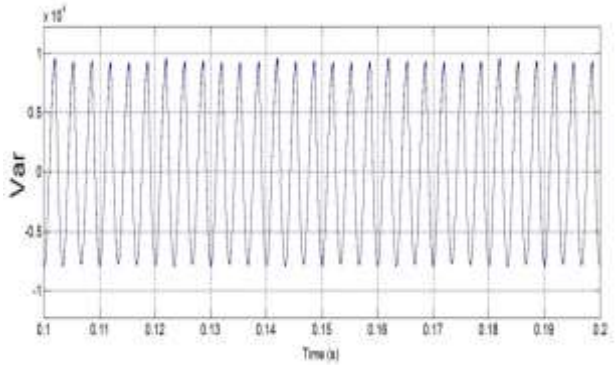


Fig. 12 Instantaneous reactive power waveform

Fig. 13 illustrates the reference current for each phase, thus it will be used as an input to 2 kHz PWM which will be used to firing 3 arms 6 pulses GTO/Diode to inject the active filter current to the network.

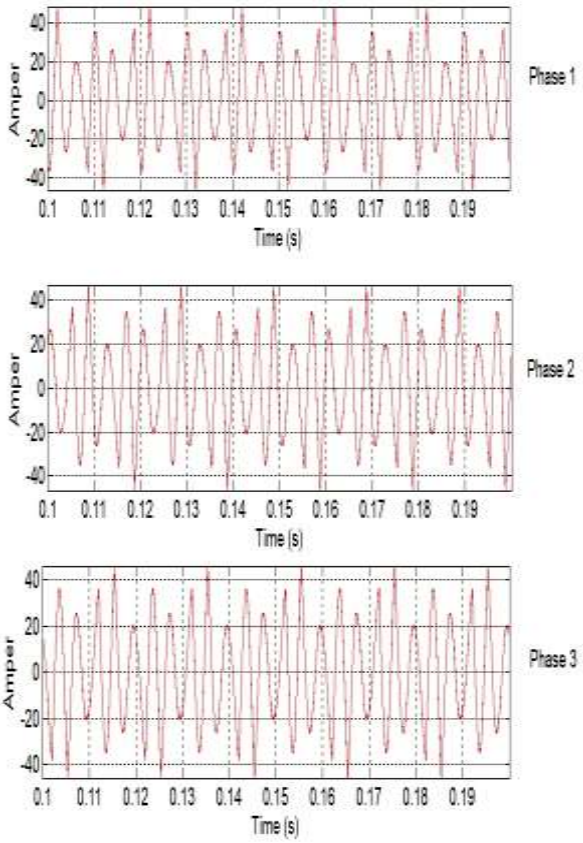


Fig. 13 Reference current for each phase

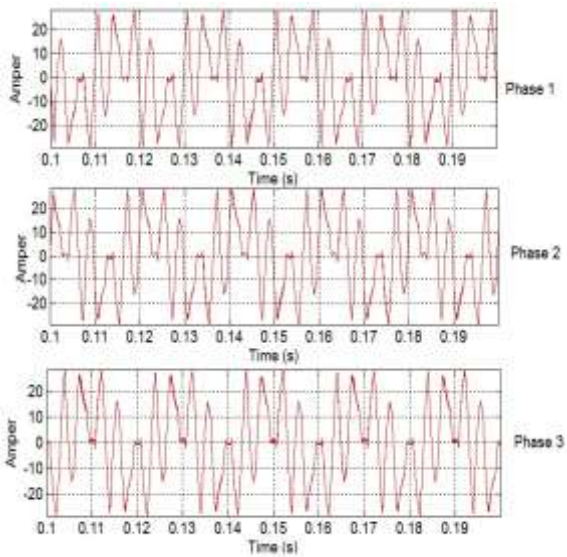


Fig. 14 Active filter current for each phase

Fig. 14 illustrates the active filter current for the three phases. The effect of the active filter on the current source is shown in Fig. 15. The APF circuit breaker is closed after 0.1 sec thus it mitigates the

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effect of harmonics source current.

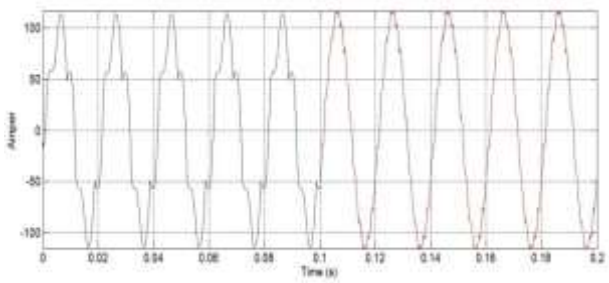


Fig. 15 Effect of active power filter on source current

The source current waveform after using APF is analysed using FFT. FFT analysis of the source current after using NARX based harmonic extraction APF are illustrated in Fig. 16 and the effect of APF can be summarized in the following data. The THD of source current is decreased from 18.53 % to 4.03%. It is illustrated also that, 5th harmonic is decreased from 17.35% to 0.76%, the 7th harmonic is decreased from 5.67% to 0.91% and the 11th harmonic is decreased from 2.41% to 2.1%.

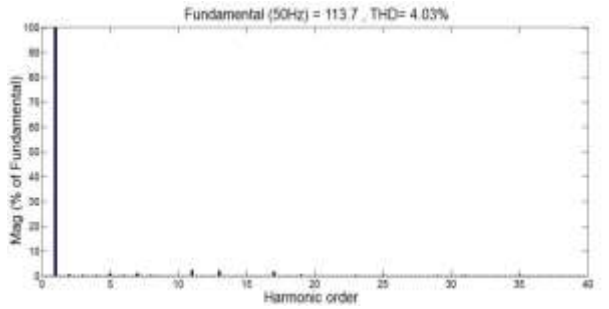


Fig. 16 FFT of source current after using NARX based harmonic extraction APF

5.Conclusion

This paper presents a novel shunt active power filter control reference signal using Nonlinear Autoregressive with eXogenous neural network NARX with backpropagation training algorithm. A method for predicting the true harmonics of nonlinear load in distributed electric power system using artificial neural network. The test results demonstrate the effectiveness the proposed method and have a good performance for current harmonic cancellation, and thus justifying accuracy and reliability of the proposed NARX network. The proposed NARX have the possibility to be used for on-line harmonic prediction and in turn provide a good control tool for shunt active power filter.

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