HARMONIC CURRENT COMPENSATION IN ACTIVE POWER FILTER BASED ON ADAPTIVE NEURAL NETWORK

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Abstract: *an essential role is played by Shunt active power filters (SAPF) in harmonic elimination as well as reactive power compensation in power systems with a large concentration of non-linear loads. Commonly, the (SAPF) efficiency depends on three design criteria: (1) types of current controllers; (2) methods used to obtain the reference current; (3) DC link voltage control methods. In this paper, a comparison between two strategies for extracting the three-phase reference currents for shunt active power filters is shown ;artificial neural network (ANN) and p-q theory. The two strategies performance will be evaluated at the supply current quality rank and system stability at DC link capacitor which ensures suitable transit of powers to supply the inverter. The study has been accomplished using simulation with the MATLAB Simulink Power System Toolbox. The simulation study results of the new identification technique (ANN) are found quite satisfactory by assuring good filtering characteristics and high system stability.*

Key words: (SAPF), Harmonics, Total Harmonic Distortion, Artificial Neural Networks (ANN), p-q theory.

1. Introduction

Due to the proliferation of power electronic equipment and nonlinear loads in power distribution systems, the problem of harmonic contamination and treatment take on great significance .These harmonics interfere with sensitive electronic equipment and cause undesired power losses in electrical equipment[1-8]. In order to solve and to regulate the permanent power quality problem introduce by this Current harmonics generated by nonlinear loads such as switching power factor correction converter, converter for variable speed AC motor drives and HVDC systems, the passive filters have been used; which are simple and low cost. However, the use of passive filter has many disadvantages, such as large size, tuning and risk of resonance problems.

Lately, owing to the rapid improvement in power semiconductor device technology that makes high-speed, high-power switching devices such as power MOSFETs, MCTs, IGBTs , IGCTS , IEGTs etc. usable for the harmonic compensation modern power electronic technology, Active power filter (APF) have been considered as an effective solution for this issue, which has been widely used.

One of the most popular active filters is the Shunt Active Power Filter (SAPF) [2-7, 9]. SAPF have been researched, developed and have gradually been recognized as a workable solution to the problems created by non-linear loads. The functioning of shunt active filter is to sense the load currents and extracts the harmonic component of the load current to produce a reference current i_c^* ; a block diagram of the system is illustrated in Fig. 1. The reference current consists of the harmonic components of the load current which the active filter must supply. This reference current is fed through a controller and then the switching signal is generated to switch the power switching devices of the active filter so that the active filter will indeed produce the harmonics required by the load. Finally, the AC supply will only need to provide the fundamental component for the load, resulting in a low harmonic sinusoidal supply.

Generally, the effectiveness of SAPF depends on three design criteria: (i) design of power inverter; (ii) use of current controller's types (iii) methods used to obtain the reference current. The presented work was oriented mostly on the latter criterion.

In order to determine harmonic and reactive component of load current, reference source current generation is needed. Thus, reference filter current can be obtained when it is subtracted from total load current. For better filter performance, generation of reference source current should be done properly. For this purpose, several methods such as pq-theory, dq-transformation, multiplication with sine function and Fourier transform have been introduced in literature [9-14].

Recently, some methods based on artificial intelligence have been applied In order to improve processing detecting time of harmonic current. The past decade has seen a dramatic increase in interest Artificial Neural Networks (ANNs) which is characterized by its learning ability and high speed recognition but simple structure, the ANNs have been applied in many uses in the power electronic part of both machinery [18] and filters devices [19-26] where they have justified their effectiveness. The results obtained with ANNs are often better than those of traditional methods. Indeed, as a result of their capacities to optimize simultaneously their weights and biases in an on-line training process, they are able to adapt themselves to any system.

In this paper, a detection method using ANN is presented which is utilized in harmonic current detection from distorted wave and DC link control voltage.

This method can precisely obtain the reference current of each phase. The learning rate can be regulated in a wide range with little affection on the performance with a simple structure and theory [19-26]. The performances of the Neural Method are evaluated under simulation and are compared with p-q theory.

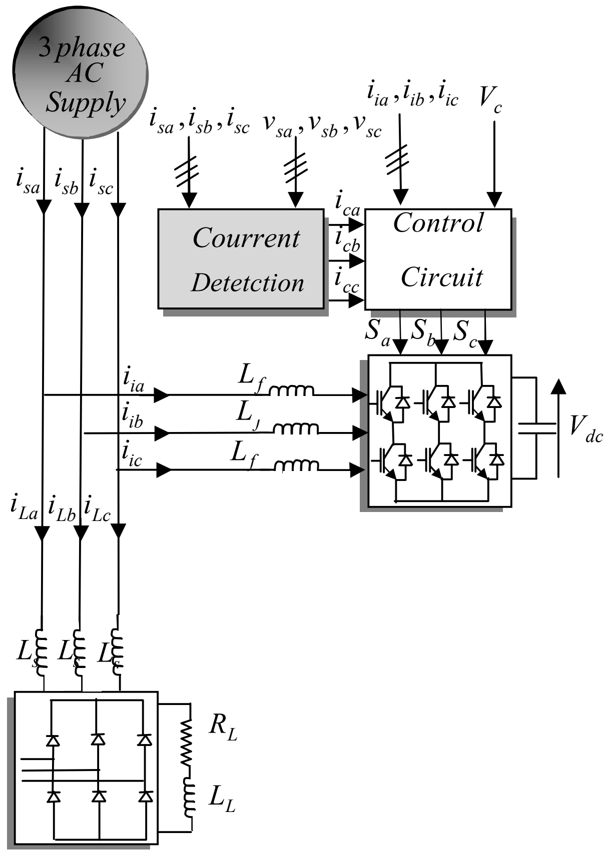

Fig.1. Schematic diagram of shunt APF

2. Reference Source Current Generation

The concept of instantaneous reactive power theory (p-q theory), method basically consists of a variable transformation from the a, b, c reference frame of the instantaneous power, voltage and current signals to the $\alpha-\beta$ reference frame [13.14]. The instantaneous values of voltages and currents in the $\alpha-\beta$ coordinates can be obtained from the following equations:

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = [A] \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix}, \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = [A] \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (1)$$

where A is the transformation matrix and is equal to:

$$[A] = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \quad (2)$$

This transformation is valid if and only if $v_a(t)+v_b(t)+v_c(t)=0$ and also if the voltages are balanced and sinusoidal. The instantaneous active and reactive powers in the $\alpha-\beta$ coordinates are calculated with the following expressions:

$$p(t) = v_\alpha(t) i_\alpha(t) + v_\beta(t) i_\beta(t) \quad (3)$$

$$q(t) = v_\alpha(t) i_\beta(t) - v_\beta(t) i_\alpha(t) \quad (4)$$

The values of p and q can be expressed From Eqs.(3) and (4) in terms of the dc components plus the ac components, that is:

$$p = \overline{p} + \widetilde{p} \quad (5)$$

$$q = \overline{q} + \widetilde{q} \quad (6)$$

where:

$\overline{p}$: is the dc component of the instantaneous power p, and is related to the conventional fundamental active current.

$\widetilde{p}$: is the ac component of the instantaneous power p, it does not have average value, and is related to the harmonic currents caused by the ac component of the instantaneous real power.

$\overline{q}$: is the dc component of the imaginary instantaneous power q, and is related to the reactive power generated by the fundamental components of voltages and currents.

$\tilde{q}$: is the ac component of the instantaneous imaginary power q, and is related to the harmonic currents caused by the ac component of instantaneous reactive power.

In order to compensate reactive power and current harmonics generated by nonlinear loads, the reference signal of the shunt active power filter must include the values of $\tilde{p}$ and $\tilde{q}$. [6]In this case the reference currents required by the SAPF are calculated with the following expression:

$$\begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} = \frac{1}{v_{\alpha}^{2}+v_{\beta}^{2}} \begin{bmatrix} v_{\alpha} & v_{\beta} \\ v_{\beta} & -v_{\alpha} \end{bmatrix} \begin{bmatrix} \tilde{P}_{L} \\ \tilde{q}_{L} \end{bmatrix} \qquad (7)$$

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

$$\begin{bmatrix} i_{ca}^{*} \\ i_{cb}^{*} \\ i_{cc}^{*} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{c\alpha}^{*} \\ i_{c\beta}^{*} \end{bmatrix} \qquad (8)$$

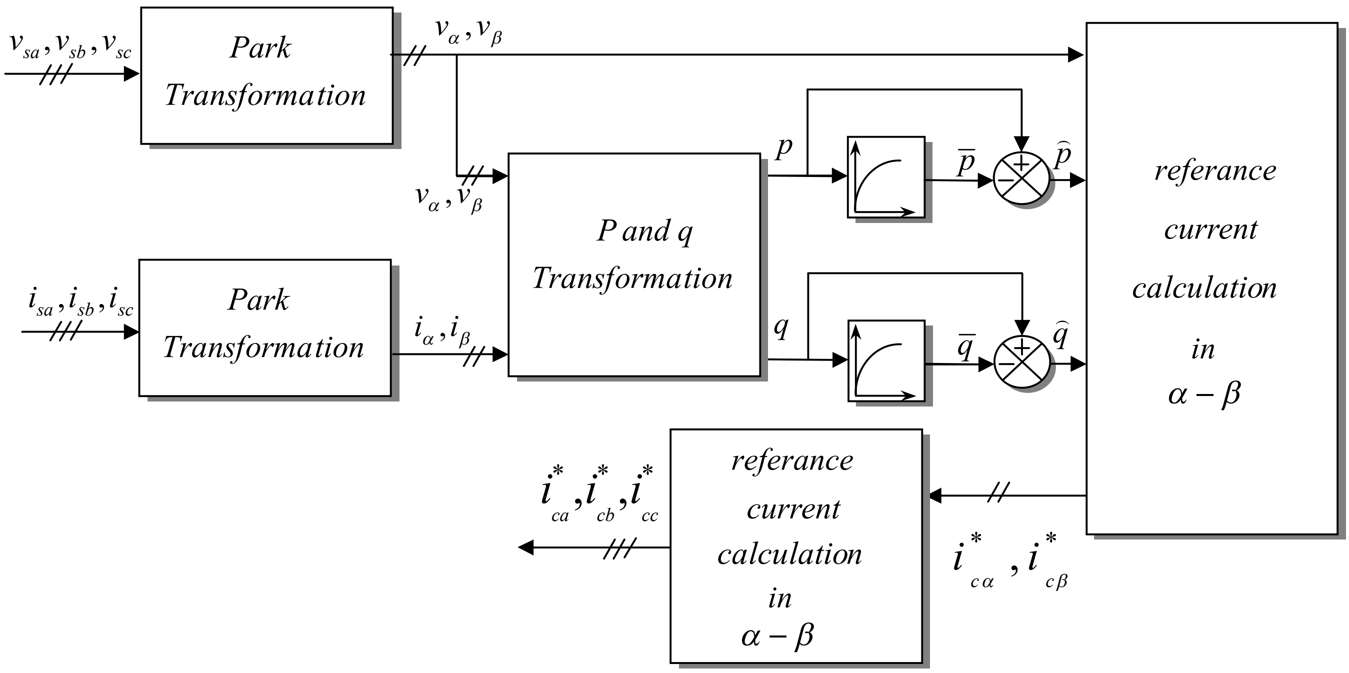

Fig.2. Block diagram for the instantaneous active and reactive power

The SAPF control strategy involves not only the production of currents whether to eliminate the undesired harmonics or to compensate reactive power, but also to recharge the capacitor value requested by VDC voltage in order to ensure suitable transit of powers to supply the inverter[9-13]. The storage capacity C absorbs the power fluctuations caused by the compensation of the reactive power, the presence of harmonics, and the active power control and also by the losses of the converter. The average voltage across the capacitor terminals must be kept at a constant value. The regulation of this voltage is made by absorbing or providing active power on the electrical network. The correction of this voltage must be done by adding the fundamental active current in the reference current of SPAF. To realize these objectives, a controller as shown in Figure.3 is added to regulate the capacitor dc voltage of the SAPF. In this circuit, the actual dc capacitor voltage is detected and compared with the reference value, and the error is amplified then added to the $\tilde{p}_{L}$, the output of high-pass filter in Figure. 2. Therefore, active power allowed into the capacitor is being changed and the dc voltage is controlled.

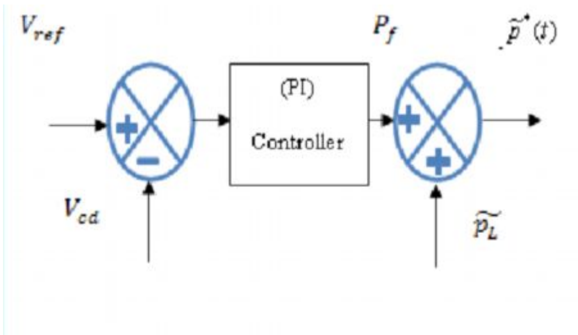

Fig.3. Control of DC Voltage

3. Neural Networks For Reference Source Current And Dc Voltage Control

In this work, the p-q theory is modeled, as depicted in Fig. 4, by an artificial neural network ANN made up of two hidden layers with 12 neurons each, and one output layer with 3 neurons. The logarithmic activation function is the base of the two hidden layers neurons, and linear activation function for the output layer neurons.

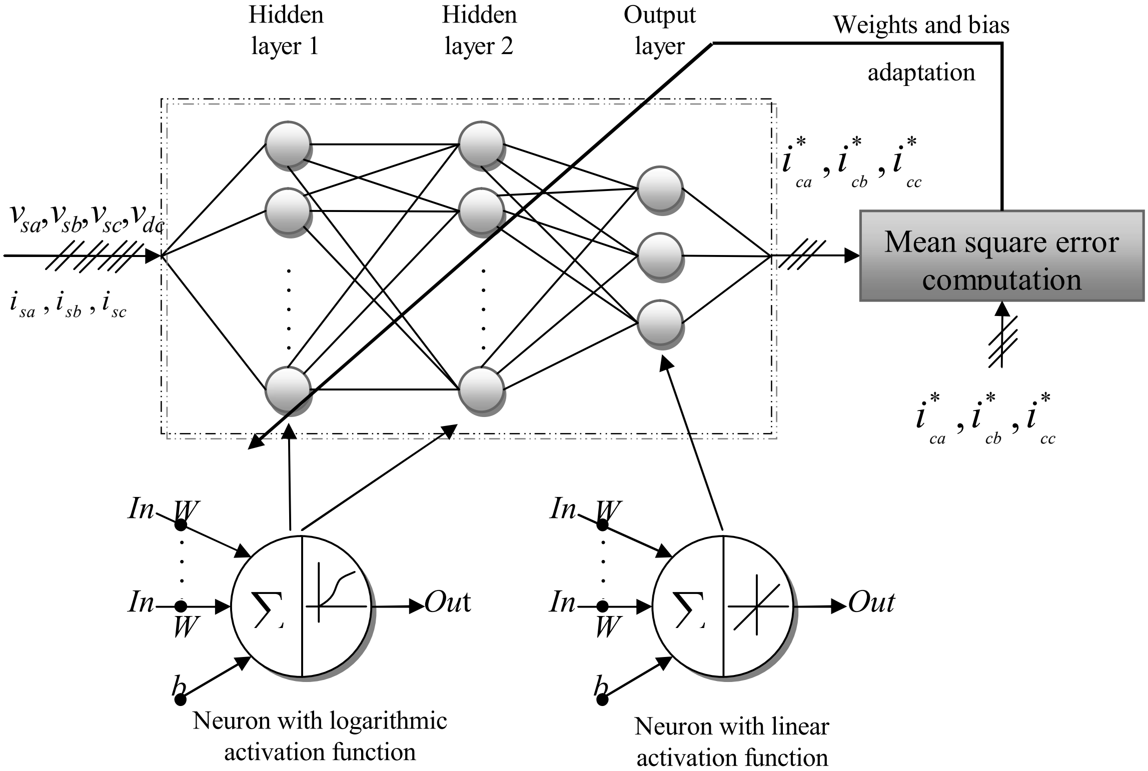

Fig.4. Neural network for (p-q theory) modeling

The ANN in Fig. 4 has seven inputs (v_{sa}, v_{sb}, v_{sc}, v_{dc}, i_{sa}, i_{sb}, i_{sc},) and three outputs (i^*_{ca} , i^*_{cb} , i^*_{cc}) , as observed in the p-q theory. The model of the neurons of the hidden layers is represented in Fig.4, where each neuron has n inputs. This parameter varies in function of the chosen hidden layer, where n equals 7 if the neuron belongs to hidden layer 1, and n equals 12 if the neuron belongs to hidden layer 2. For the neurons of the output layer, n equals 12.

The adaptation of the weights (W) and bias (b) in the ANN, is based, first, on the computation of the mean square error (MSE) between the outputs of the PQ technique and those of the ANN, and secondly, on the execution of 'Levenberg-Marquardt backpropagation' algorithm [20-26].

4. Simulation Results

The performance of the proposed detection method using ANN was examined through simulations. The system model was implanted in Matlab / Simulink environment. The SAPF was designed to compensate harmonics caused by nonlinear loads. The system model parameters are shown in Table 1.

A three-phase diode rectifier with an RL load was used as a harmonic producing load. The load value is (resistance was 10/3 Ω and the inductance 60 mH. or Load apparent power SL=82VA).

Table 1 System Parameters

Parameters	
Supply phase voltage U	220 V
Supply frequency fs	50 Hz
Filter inductor Lf	0.7 mH
Dc link capacitor Cf	0.768474 mF
Vdc	850V

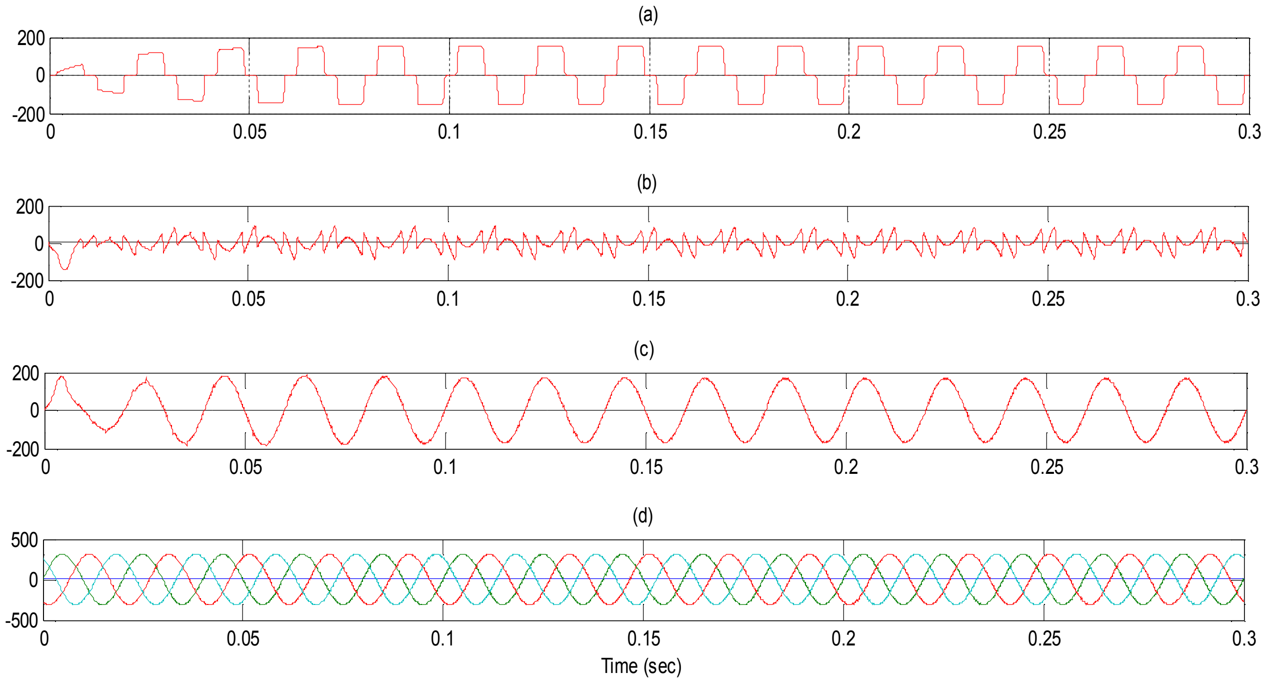

Fig.5. (a) Simulated phase-a load current waveforms, (b) Simulated phase-a reference current waveforms , (c) Simulated phase-a the supply current waveforms , (d) Simulated the supply voltage waveforms with a (p-q theory) method

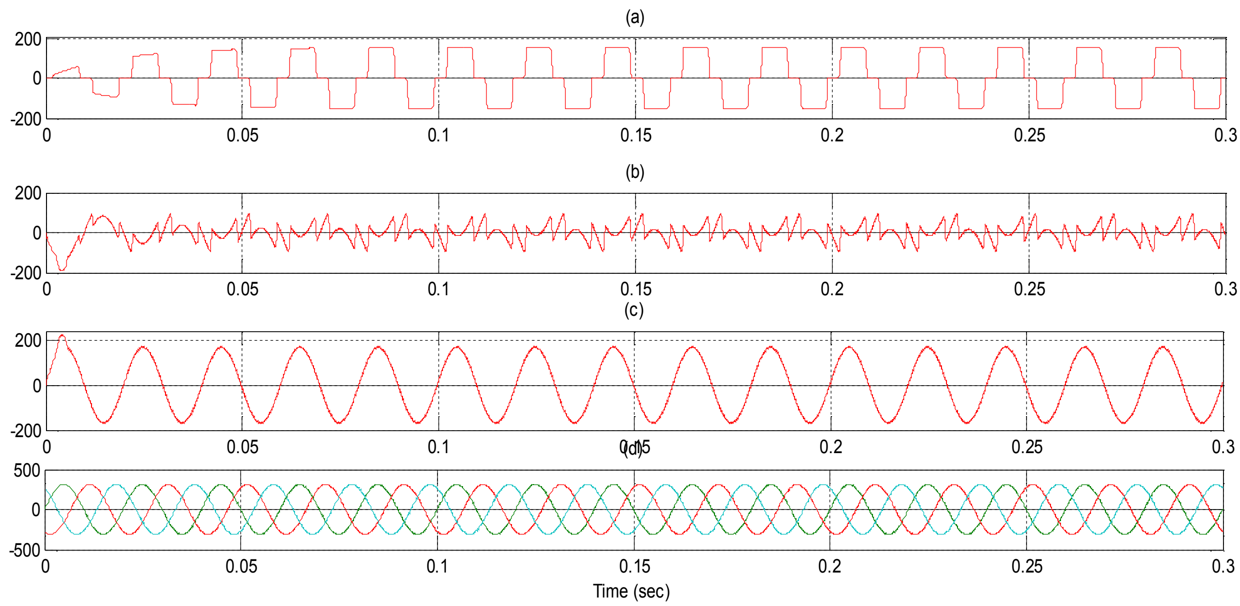

Fig.6. (a) Simulated phase-a load current waveforms, (b) Simulated phase-a reference current waveforms , (c) Simulated phase-a the supply current waveforms , (d) Simulated the supply voltage waveforms with a ANN method

Table 2
Harmonic Supply Current Phase-A-Component

Harmonic Supply Current Components Isa(n)/Isa(1) [%]			
n	load	p-q theory	(ANN) method
5	19.59	0.37	0.28
7	13.56	0.43	0.37
11	8.06	0.17	0.04
13	6.48	0.27	0.24
17	4.38	0.41	0.06
19	3.63	0.21	0.17
23	2.51	0.11	0.06
25	2.08	0.15	0.12
29	1.43	0.21	0.04
31	1.18	0.05	0.08
35	0.82	0.07	0.04
37	0.70	0.03	0.05
41	0.56	0.16	0.03
43	0.51	0.01	0.05
47	0.46	0.11	0.04
49	0.44	0.05	0.05
THD	26.91	1.05	0.74

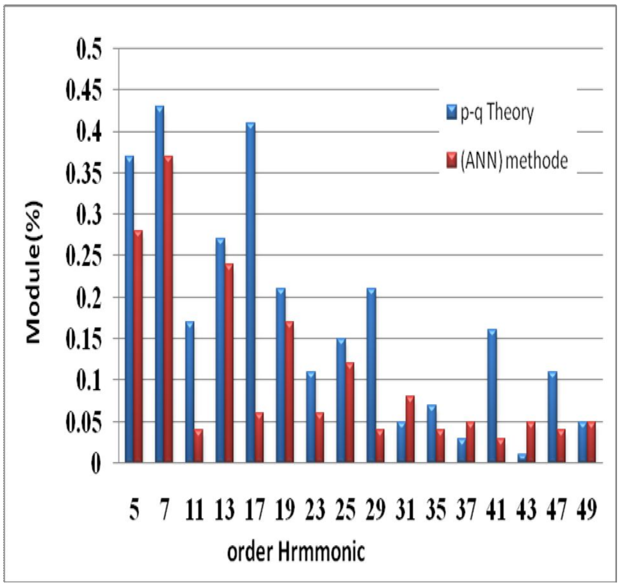

Fig.7. Harmonic spectrum of supply current Phase 'a'

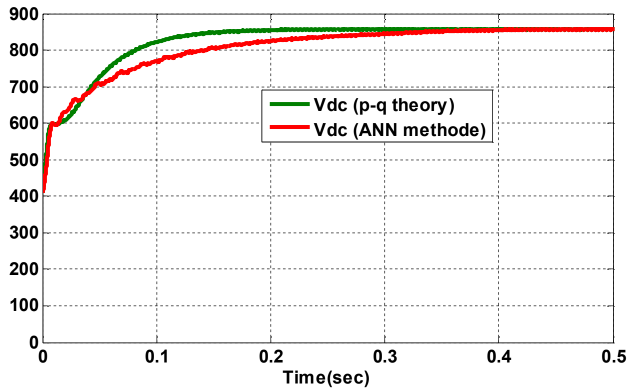

Fig.8.DC link voltage regulation comparison between (p-q theory) and ANN

Table .3.
Performance indices, system with the two methods

	(ANN) Case	(p-q theory) Case
Rise Time	0.1488	0.08598
overshoot	0%	0%
Settling Time(s)	0.15	0.42
Steady-state Error	0.3280%	0.3301%

In simulations the two different identification methods were used .Because of the ANNs capacities to optimize simultaneously their weights and biases in an on-line training process; this approach improves the SAPF performance. The filtering result can be seen in Figure 5and 6. The deformations have now been reduced and the harmonic distortion calculated up to 2.5 kHz (THD2.5kHz) has been weakened. Although the filtering performance especially with the low order harmonics has been improved, this can be seen in Table II, where the THD calculated up to 2.5 kHz remains less than the case of (p-q theory) approach.

Figure 8 represents the controlled voltage on the borders of the condenser. We compare the pro-posed approach ANN and the case of the PI controller which is incorporated in (p-q theory) as shown in Table III It seems clearly that the PI controller in (p-q theory) is characterized by a very low Rising Time and Settling Time (Tr is equal to 0.08598 s, Ts is equal to 0.15 s) compared to the ANN case (Tr is equal to 0.1488 s, Ts is equal to 0.42 s). The former case presents acceptable results at the level of DC voltage control.

5. Conclusion

The work presented in this paper makes a significant contribution to the identification and control strategies in order to improve the SAPF performance. The novel approach which is based on intelligent neural techniques has been proposed. The performance of the proposed ANN was verified through simulation studies with Matlab and confronted with classical techniques. The complete SAPF structure has been implanted to compensate harmonics caused by nonlinear loads.

At this level, comparative studies between the neural approach and one of the most conventional techniques used to extract the harmonic component of the load current to produce reference currents; (p-q theory) have been accomplished. The achieved results can assert that all the identifying objectives of the harmonic currents can be satisfied by the approach based on neural networks. However, the (p-q theory) merit is that the latter contains integrated (PI) controller, added to regulate the capacitor dc voltage of the SAPF.

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