International Journal of Electrical and Power Engineering 7 (3): 71-75, 2013
ISSN: 1990-7958

Power Quality Improvement Using ANN Logic Based UPQC

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Abstract: A Unified Power Quality Controller (UPQC) using a Aritifical Neural Network (ANN) has been proposed. The results obtained through the ANN are good in terms of dynamic response because of the fact that the ANN is based on linguistic variable set theory and does not require a mathematical model of the system. Moreover, the tedious method of tuning the PI controller is not required in case of ANN. Simulations are carried out using MATLAB/Simulink to validate the theoretical findings.

Key words: Unified power quality controller total harmonics distortioncomponent, harmonics, PI controller, reactive power, artifical neural network controller

INTRODUCTION

There has been a continuous rise of nonlinear loads over the years due to intensive use of power electronic control in industry, as well as by domestic consumers of electrical energy. The utility supplying these nonlinear loads has to supply large vars. Moreover, the harmonics generated by the nonlinear loads pollute the utility. The basic requirements for compensation process involve precise and continuous VAR control with fast dynamic response and on-line elimination of load harmonics. To satisfy these criterion, the traditional methods of VAR compensation using switched capacitor and thyristor controlled inductor (Gyugyi, 1979; Jin *et al.*, 1994; Mahanty, 2008) coupled with passive filters are increasingly replaced by Active Power Filters (APFs) (Hirve *et al.*, 2007; Lascu *et al.*, 2007; Montero *et al.*, 2007; Singh *et al.*, 2004; Casaravilla *et al.*, 2002). The APFs are of 2 types, the shunt APF and the series APF. The shunt APFs are used to compensate current related problems, such as reactive power compensation, current harmonic filtering, load unbalance compensation, etc. The series APFs are used to compensate voltage related problems, such as voltage harmonics, voltage sag, voltage swell, voltage flicker, etc. The Unified Power Quality Conditioner (UPQC) aims at integrating both shunt and series APFs through a common DC link capacitor. The UPQC is similar in construction to a Unified Power Flow Controller (UPFC) (Gyugyi, 1992). The UPFC is employed in power transmission system whereas the UPQC is employed in a power distribution system. The primary objective of UPFC is to control the flow of power at fundamental frequency. On the other hand, the UPQC controls distortion due to harmonics and unbalance in voltage in addition to control of flow of power at the fundamental frequency. The schematic block diagram of UPQC is shown in Fig. 1. It consists of 2 Voltage Source Inverters (VSIs) connected back-to-back, sharing a common DC link in between. One of the VSIs act as a shunt APF whereas the other as a series APF. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. Control schemes of UPQC based on PI controller has been widely reported (Wang *et al.*, 2005; Khadkikar and Chandra, 2008; Kolhatkar and Das, 2007; Basu *et al.*, 2007). The PI control based techniques are simple and reasonably effective. However, the tuning of the PI controller is a tedious job. Further, the control of UPFC power quality improvement using fuzzy logic based UPQC. Based on the conventional PI control is prone to severe dynamic interaction between active and reactive power flows (Wang *et al.*, 2005). In this research, the conventional PI controller has been replaced by a ANN Controller (ANNC). The ANNC has been used in APFs in

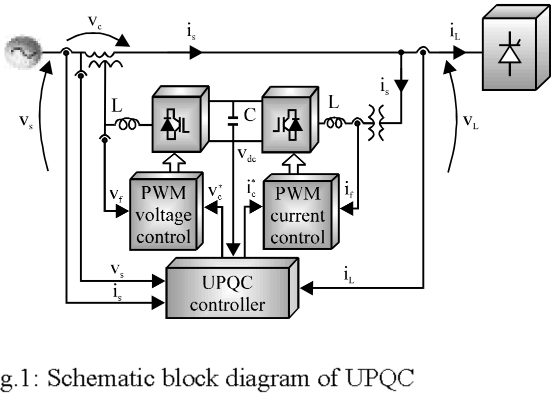

Fig.1: Schematic block diagram of UPQC

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place of conventional PI controller for improving the dynamic performance (Saerens and Soquet, 1991; Hagan *et al*., 1996). The ANNC is basically nonlinear and adaptive in nature. The results obtained through ANNC are superior in the cases where the effects of parameter variation of controller are also taken into consideration. The ANNC is based on linguistic variable set theory and does not require a mathematical model. Generally, the input variables are error and rate of change of error. If the error is coarse, the ANNC provides coarse tuning to the output variable and if the error is fine, it provides fine tuning to the output variable. In the normal operation of UPQC, the control circuitry of shunt APF calculates the compensating current for the current harmonics and the reactive power compensation. In the conventional methods, the DC link capacitor voltage is sensed and is compared with a reference value. The error signal, thus derived is processed in a controller. A suitable sinusoidal reference signal in-phase with the supply voltage is multiplied with the output of the PI controller to generate the reference current. Hysteresis band is normally (most often but not always) is imposed on top and bottom of this reference current. The width of the hysteresis band is so adjusted such that the supply current Total Harmonic Distortion (THD) remains within the international standards. The function of the series APF in UPQC is to compensate the voltage. The control circuitry of the series APF calculates the reference voltage to be injected by the series APF by comparing the terminal voltage with a reference value of voltage.

CONTROL STRATEGY OF UPQC

The sensed DC link voltage v_{dc} is compared with a reference voltage v_{dc}^*. The error signal obtained is processed in ANN controller. The output of the ANN controller i_{sb}^* is considered as the magnitude of 3-phase reference supply currents. The 3-phase unit current vectors (u_{sa}, u_{sb}, u_{sc}) are derived in phase with the 3-phase supply voltages (u_{sa}, u_{sb}, u_{sc}). The unit current vectors from the 3-phase of supply currents. Multiplication of magnitude i_{sb}^* with (u_{sa}, u_{sb}, u_{sc}) results in 3-phase reference supply currents (i_{sa}^*, i_{sb}^*, i_{sc}^*). Subtraction of load currents (C) from the reference currents, results in 3-phase reference currents (i_{sha}^*, i_{shb}^*, i_{shc}^*) for the shunt APF. These reference currents are compared with the actual shunt compensating currents (i_{sha}, i_{shb}, i_{shc}) and the error signal is converted into PWM gating signals, the shunt APF supplies harmonics currents and reactive power demand of the load.

The amplitude of the supply voltage is computed from the 3-phase sensed values of voltages as:

$$V_{sm} = \left[\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)\right]^{\frac{1}{2}} \tag{1}$$

The 3-phase unit current vectors are computed as:

$$u_{sa} = \frac{v_{sa}}{v_{sm}},\ u_{sb} = \frac{v_{sb}}{v_{sm}},\ u_{sc} = \frac{v_{sc}}{v_{sm}} \tag{2}$$

Multiplication of 3-phase unit current vectors (u_{sa}, u_{sb}, u_{sc}) with the amplitude of the supply current (i_{sp}) results in 3-phase reference supply currents as:

$$i_{sa}^* = a,\ i_{sb}^* = b,\ i_{sc}^* = c \tag{3}$$

Where:

$a = i_{sp}.\ u_{sa}$

$b = i_{sp}.\ u_{sb}$

$c = i_{sp}.\ u_{sc}$

To obtain reference currents, 3-phase load currents are subtracted from 3-phase supply currents as:

$$i_{sha}^* = a_1,\ i_{shb}^* = b_1,\ i_{shc}^* = c_1 \tag{4}$$

Where:

$a_1 = i_{sa}^* - i_{la}$

$b_1 = i_{sb}^* - i_{lb}$

$c_1 = i_{sc}^* - i_{lc}$

Principle of control of series APFs: In the series APF, the 3 load voltages (v_{la}, v_{lb}, v_{lc}) and are subtracted from three supply voltages (v_{sa}, v_{sb}, v_{sc}) resulting into 3-phase reference voltages (v_{la}^*, v_{lb}^*, v_{lc}^*) to be injected in series with the load. By taking a suitable transformation, the three reference currents (i_{sea}^*, i_{seb}^*, i_{sec}^*) of the series APF are obtained from the 3-phase reference voltages (v_{ia}^*, v_{ib}^*, v_{ic}^*). The reference currents are fed to a current controller along with their sensed counterparts (i_{sea}, i_{seb}, i_{sec}). Supply voltage and load voltage are sensed and there from the desired injected voltage is computed as:

$$V_{inj} = v_s - v_l \tag{5}$$

The 3-phase reference values of injected voltage are expressed as:

$$V_{ia}^* = \sqrt{2}V_{inj}\sin\left(\omega t + \delta_{inj}\right) \tag{6}$$

$$V_{ib}^* = \sqrt{2}V_{inj}\sin\left(\omega t + \frac{2\pi}{3}\delta_{inj}\right) \tag{7}$$

$$V_{ic}^{*} = \sqrt{2}V_{inj}\sin\left(\omega t + \frac{2\pi}{3}\delta_{inj}\right) \tag{8}$$

Where, δ_{inj} is the phase of the injected voltage. The 3-phase reference currents of the series APF are computed as follows:

$$i_{sea} = \frac{V_{ia}^{*}}{Z_{se}},\ i_{seb} = \frac{V_{ib}^{*}}{Z_{se}},\ i_{sec} = \frac{V_{ic}^{*}}{Z_{se}} \tag{9}$$

The impedance Z_{se} includes the impedance of the transformer inserted. The currents (i_{sea}^{*}, i_{seb}^{*}, i_{sec}^{*}) are the ideal currents to be maintained through the secondary winding of the transformer in order to inject voltages (v_{1a}, v_{1b}, v_{1c}) there by accomplishing the desired task of voltage sag compensation the currents (i_{sea}^{*}, i_{seb}^{*}, i_{sec}^{*}) are compared with series compensating currents in the PWM current (i_{sha}^{*}, i_{shb}^{*}, i_{shc}^{*}) controller for obtaining signals for the switches in inverter.

THE STRUCTURE OF ANN

Neural networks are models of biological neural structures. The starting point for most neural networks is a model neuron, as in Fig. 2. This neuron consists of multiple inputs and a single output. Each input is modified by a weight which multiplies with the input value. The neuron will combine these weighted inputs and with reference to a threshold value and activation function, use these to determine its output. This behavior follows closely the understanding of how real neurons work.

While there is a fair understanding of how an individual neuron works, there is still a great deal of research and mostly conjecture regarding the way neurons organize themselves and the mechanisms used by arrays of neurons to adapt their behavior to external stimuli. There are a large number of experimental neural network structures currently in use reflecting this state of continuing research.

In the case, researchers will only describe the structure, mathematics and behavior of that structure known as the back propagation network. This is the most prevalent and generalized neural network currently in use.

To build a back propagation network, proceed in the following fashion. First, take a number of neurons and array them to form a layer. A layer has all its inputs connected to either a preceding layer or the inputs from the external world but not both within the same layer.

A layer has all its outputs connected to either a succeeding layer or the outputs to the external world but not both within the same layer.

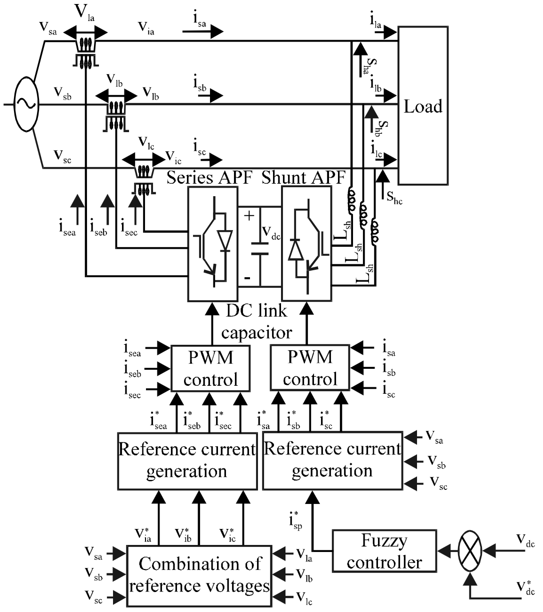

Fig. 2: Control scheme of three-phase UPQC

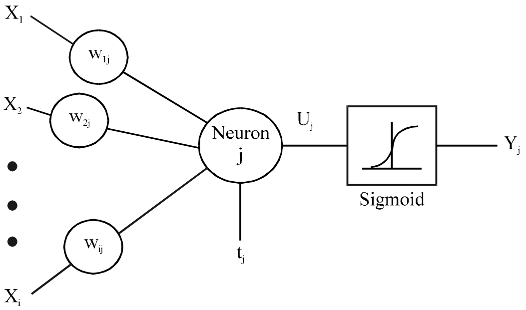

Fig. 3: Model of neural

Next, multiple layers are then arrayed one succeeding the other so that there is an input layer, multiple intermediate layers and finally an output layer, as in Fig. 3. Intermediate layers that are those that have no inputs or outputs to the external world are called hidden layers.

Back propagation neural networks are usually fully connected. This means that each neuron is connected to every output from the preceding layer or one input from the external world if the neuron is in the first layer and correspondingly, each neuron has its output connected to every neuron in the succeeding layer (Fig. 4).

Generally, the input layer is considered a distributor of the signals from the external world. Hidden layers are considered to be categorizers or feature detectors of such signals.

$$Y_j = F_{th}(U_j + t_j)$$

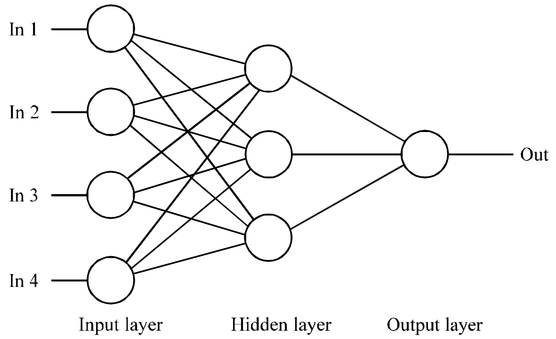

Fig. 4: Backpropagation network

The output layer is considered a collector of the features detected and producer of the response. While this view of the neural network may be helpful in conceptualizing the functions of the layers, you should not take this model too literally as the functions described may not be so specific or localized.

SIMULATION RESULTS

In order to test the performance of the UPQC using the proposed ANNC, it has been simulated for a 400 V, 50 Hz 3-phase AC supply using MATLAB/Simulink. A 3-phase diode rectifier feeding an RL load is considered as nonlinear load. The maximum load power demand is considered as 13 kW+j10 kVAR. The values of source resistance Rs = 0.1 Ω and source inductance Ls = 0.1 mH. DC link capacitor value is 2200 μF. To test the operation of UPQC under the voltage sag and swell conditions, 20% sag in line voltage has been created. The UPQC has been simulated using the proposed ANNC. The source current waveform before and after connecting the UPQC is shown in Fig. 5 and 6. It may be noticed that the source current is distorted before connecting the UPQC and it becomes sinusoidal after connecting the UPQC at 0.1 sec.

The THD of the source current before connecting the UPQC is 24.54%. Harmonic spectrum of the source current after connecting the UPQC is shown in Fig. 7. The THD of the source current after connecting the UPQC is 0.06. The DC link capacitor voltage is held constant at its reference value by the ANNC. To investigate the performance of the proposed UPQC using ANNC, under voltage sag condition, 20% sag has been created in the all the phases of the supply voltage. The simulation results of these cases are shown in Fig. 5 and 6.

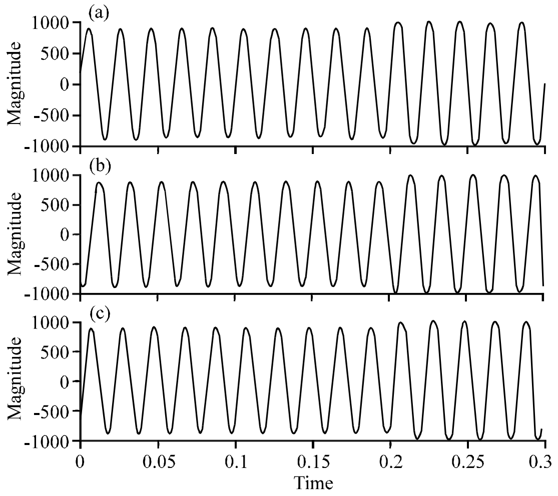

Fig. 5: Voltage waveforms of the system without UPQC: a) v_a; b) v_b; c) v_c

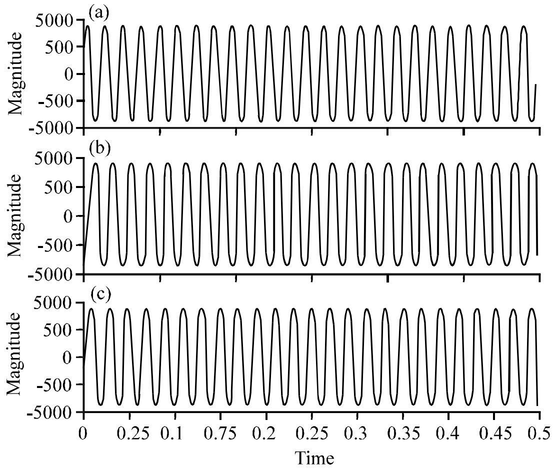

Fig. 6: Voltage waveforms with ANNC controlled UPQC: a) v_a; b) v_b; c) v_c

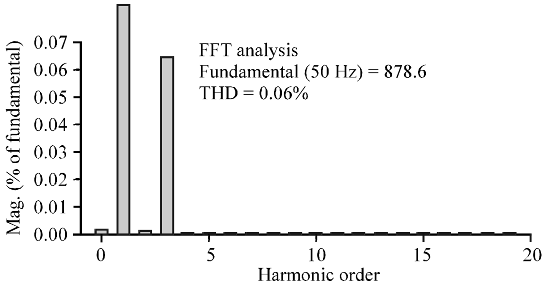

Fig. 7: Total harmonic distortion of system with ANNC

CONCLUSION

UPQC using ANNC has been investigated for compensating reactive power and harmonics. It is clear from the simulation results that the UPQC using ANNC is simple and is based on sensing the line currents only. The THD of the source current using the proposed ANNC is well below 5%, the harmonic limit imposed by IEEE-519 standard.

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