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INVESTIGATION OF UPQC PERFORMANCE USING PI AND ANN CONTROLLER

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Abstract: -
Power Quality in electrical networks is one of the most concerned areas of preset electrical power systems. Unified Power Quality Conditioner (UPQC) is the most efficient and effective modern custom power device used in power distribution networks. A reliable control algorithm provides best performance of UPQC and at the same time the switching circuit should have fast response procedures. Artificial neural network (ANN) is considered as a new tool to design control circuitry for power quality (PQ) devices. In this paper, an ANN based controller is designed for the current control of the shunt active power filter, and is trained offline using data from the conventional proportional-integral (PI) controller. Performance of UPQC using PI controller and ANN controller are studied and compared. This performance study is carried out using MATLAB simulations.

Keywords: *Power Quality (PQ), unified power quality conditioner (UPQC), Artificial intelligence (AI), artificial neural network (ANN), Current source inverter (CSI), proportional integral (PI), VSI.*

1. INTRODUCTION

Power quality issues are becoming more significant these days because of increase in usage of electronic loads and converters which behave as non-linear loads on the distribution network.

Use of electronic controllers causes intense distortions in the power systems as they act as nonlinear loads and introduce unwanted harmonics in the supply system. Efficiency of supply network and equipment as well will be reduced as a result of harmonics. To meet the requirements of harmonic regulation, passive and active power filters are being used in combination with the conventional converters. 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 APFs also act as power-conditioning devices which provide number of functions such as harmonic filtering, damping, isolation and termination, load balancing, reactive-power control for power-factor correction and voltage regulation, voltage-flicker reduction. Sometimes the functioning also includes more than one or two combinations of the above said functions. Resent research focuses on use of the unified power quality conditioner (UPQC) to compensate power-quality problems. The performance of UPQC mainly depends upon how accurately and quickly reference signals are derived. After efficient extraction of the distorted signal, a suitable dc-link current regulator is used to derive the actual reference signals. Various control approaches, such as the PI, PID, fuzzy-logic, sliding-mode, predictive, unified constant frequency (UCF) controllers are in use. Similar to the PI conventional controller, the PID controller requires precise linear mathematical models which are difficult to obtain and fails to perform satisfactorily under parameter variations, nonlinearity and load disturbances etc. Also, conventional controllers require precise mathematical models and are therefore sensitive to parameter variations. In recent years, Artificial-intelligence (AI) techniques particularly the neural networks (NN) are creating impact in power electronics applications. Neural network-based controllers provide fast dynamic response while maintaining the stability of the converter system over a wide operating range and are considered as a new tool to design control circuits for power quality (PQ) devices. Over the last few years, major research works have been carried out on control circuit design for UPQCs with the objective of obtaining reliable control algorithms and fast response procedures to obtain the switch control signals.

Vadirajacharya G. Kinhal, et al. [1] designed a ANN-based controller for the current control of shunt active power filter and trained offline using data from the conventional proportional-integral controller. Unified power quality conditioner which aimed at the integration of series-active and shunt active filters is studied and designed by Hideaki Fujita, and Hirofumi Akagi, et al. [2] to compensate voltage flicker/imbalance, reactive power, negative sequence current, and harmonics. They discussed the control strategy of the UPQC with a focus on the flow of instantaneous active and reactive powers inside the UPQC. Application of neural network control algorithms such as model reference control (MRC) and Nonlinear Autoregressive-Moving Average (NARMA)–L2 control to generate switching signals for the series compensator of the UPQC system are presented by Moleykutty George, [3] et al. L. Dinesh, S. Srinivasa Rao and N. Siva Mallikarjuna Rao [4] designed a fuzzy logic controller with reference signal generation method for UPQC and compared its performance with artificial neural network-based controller. To eliminate harmonic current and harmonic voltage in power system simultaneously and enhance the capacity, the paper [5] presented a hybrid unified power quality conditioner (HUPQC). Compared with UPQC, the HUPQC is made up of a hybrid series active power filter (the series device) and a shunt active power filter (the shunt device). The shunt device employs an injection circuit to lower the capacity of the active part to fit high-voltage power system. A new method has been offered by Kazemi, R. Rezaeipouret al.[6] to control the UPQC as a device for power quality improvement in distribution networks. Using the time domain analysis of reference signal, they instantaneously adjusted the performance of series and parallel UPQC filters such that several problems of power quality are solved. RVD Rama Rao, Dr.Subhransu, Sekhar[7] proposed a unified power quality conditioner (UPQC),which combines a shunt active filter together with a series active filter in a back to- back configuration, to simultaneously compensate the supply voltage and the load current or to mitigate any type of voltage and current fluctuations and power factor correction in a power distribution network. During fault conditions, to improve voltage profile, a Fault current limiter is designed to compensate voltage sags in single phase and three phase distribution networks in [13].

In this paper, the ANN-based controller is designed for the current control of the shunt active power filter and trained offline using data from the conventional proportional-integral controller. An algorithm for training the ANN controller is developed and trained offline.ANN controller and PI controller performances are compared using MATLAB/SIMULINK.The system configuration is described in Section 2, while PI and ANN controller designsare presented in Sections 3 and 4 respectively.Simulation and experimental results are discussed in Section 5.

2. UNIFIED POWER QUALITY CONDITIONER (UPQC)

UPQC is also known as universal power quality conditioning system.UPQC system can be divided into two sections 1.The control unit and 2.The power circuit.Control unit includes disturbance detection, reference signal generation, gate signal generation and voltage/current measurements. Power circuit consists of two voltage source converters, standby and system protection, harmonic filters and injection transformers.

The UPQC device combines a shunt active filter together with a series active filter in a back-to-back configuration to simultaneously compensate the supply voltage and current or to mitigate any type of voltage and current fluctuations and power factor correction in a power distribution network, such that improved powerquality can be made available at the point of common coupling.

CONFIGURATION OF UPQC: -A conventional UPQC topology consists of the integration of two active power filters which are connected back to back to a common dc-link bus[11]. A simple block diagram of the same is represented in Figure 1.

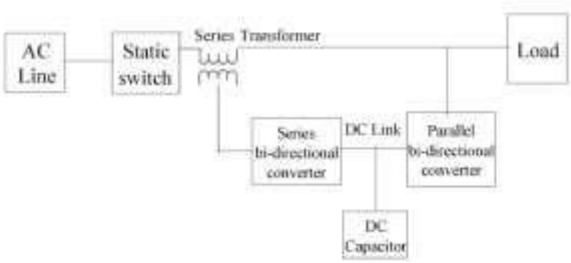

Fig. 1. Block Diagram of UPQC

UPQC can be built up as single phase configuration, three phase three wire or four wire configurations based on the design of voltage source and current source converters. Design of UPQCs with two or more VSCs are more popular and common as they are small in size and lower in cost [12]. But VSI topology has slow control of the Converter output voltage and it does not have protection against over currents or short circuits. When the active rectifier inside UPQC is used as a power factor corrector, dc bus voltage oscillations appear which makes the control of the series filter output voltage more difficult. The CSIbased UPQC has advantages of excellent Current control capability, easy protection, and high reliability Over VSI-based UPQC. The main drawback of the CSI-based UPQC has been so far the lack of proper switching devices and large dc-side filter. The new insulated-gate bipolar Transistors (IGBTs) with reverse blocking capability are being launched in the markets which are suitable for the CSI-based UPQC. With the use of Super conducting Magnetic Energy Storage (SMES) coils, the size and losses can considerably be brought down. A configuration of UPQC using two current-source converters connected back to back through a large dc-link inductor is shown in Figure 2.

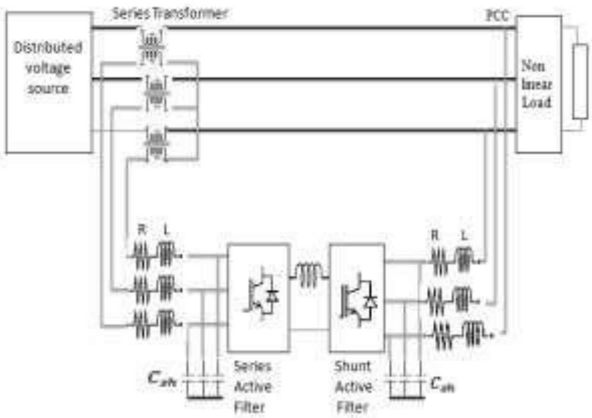

Fig.2.UPQC topology using current-source converters.

Performance of UPQC mainly depends on the accuracy and promptness in deriving the reference signals. Actual reference signals are derived from the dc-link current regulator which is designed suitably after the extraction of distorted signals. This regulator will maintain dc-link current constant for stable operation of the filter. DC Current regulator will also serve for power-loss compensation in the Filter circuits, which will take place through the activation of a shunt unit. In the conventional PI Controller, the error between the actual dc-link current and a reference Value, which is generally slightly greater than the peak of the dclink value, is fed to the PI controller. The output of the PI controller is added suitably for the generation of a reference template.

3. PI CONTROLLER

PI control with a view to have a self-regulated dc bus, the voltage across the capacitor is sensed at regular intervals and controlled by employing a suitable closed loop control. Following basic equations are used for designing the PI control System:

$$i_s = i_L - i_{inj} \quad \ldots\ldots (1)$$

$$L_{sh}\frac{d_{inj}}{dt} = v_L - i_{inj}R_{sh} = v_L - v_{sh} \quad \ldots (2)$$

To control the filter current i_{inj}, the only control Variable is the duty cycle of the PWM converter. The Problem of control is to determine the duty cycle in such a way that the dc-link current i_{dc} remains constant and to produce suitable filter current to cancel the load current harmonics. This Filter current should be opposite of the harmonic current. Thus, it is required to control two outputs, namely I_{dc} and (i_{inj}) from one control variable (i.e., the duty Cycle of the PWM converter). However, the main objective is to control the filter current, and the control strategy must lead to precise compensation of the harmonic component. Hence, (i_{inj}) is controlled indirectly by processing the actual source current and estimated reference currents in a hysteresis current controller. These reference currents are estimated by regulating dc-link current. In order to estimate the steady-state error in the dc-link current, a PI controller is used. Although the dynamic response of the Dc-link inductor has no effect on the compensation feature of the scheme, a mathematical model is required for the PI Controller. The following assumptions are made for deriving the mathematical model of the system. 1) The voltage at PCC is sinusoidal and balanced. 2) Since the harmonic component does not affect the average power balance expressions, only the fundamental component of currents is considered. 3) Losses of the system are lumped and represented by an equivalent resistance connected in series with the filter inductorL_{sh}. 4) Ripples in the dc-link current are neglected.The block diagram of the current control loop is shown in Figure 3, where G(s) is gain of the PI controller; K_c transfer function of the PWM converter. A linear model of the PWM converter can be derived by applying a small-signal perturbation technique to obtain its transfer function. In this method of deriving a linear model.

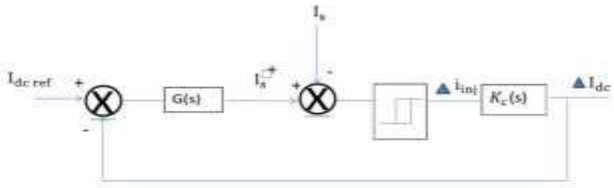

Fig.3. Block diagram of the current control loop.

The system is assumed to operate in the steady state, and the defining equations are linearised for smallsignal perturbation. The relation between the input (ac side) and output (dc-linkSide) quantities of the pwm converter are obtained by equating the rate of change of energy associated.

The average rate at which energy being absorbed by the inductor is

$$P_{ind} = \frac{d}{dt}\left(\frac{1}{2}L_{DC}I_{DC}^2\right) = L_{DC}I_{DC}\frac{dI_{DC}}{dt} \quad \ldots\ldots (3)$$

The power input to the PWM converter

$$P_{conv} = 3v_{sh}i_{inj} \quad \ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

The average rate of change of energy associated with the capacitor filter

$$P_{cap} = 3\frac{d}{dt}\left(\frac{1}{2}c_{sh}v_{sh}^2\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Power loss in the resistor R_{sh}

$$P_{loss} = 3i_{inj}^2R_{sh} \quad \ldots\ldots\ldots\ldots\ldots\ldots. (6)$$

Equating the average rate of change of the change of energy

$$P_{ind} = P_{Conv} - P_{loss} - P_{cap} \ldots\ldots\ldots.. (7)$$

On substituting the values from (3) – (7)

$$L_{DC}I_{DC}\frac{dI_{DC}}{dt} = 3\left[v_{sh}i_{inj} - i_{inj}^2R_{sh} - v_{sh}c_{sh}\frac{dv_{sh}}{dt}\right] \quad \ldots. (8)$$

In order to linearise the power equation, a small perturbation$\Delta i_{inj}$is applied in the input current of converter i_{inj}about a steady-state operating pointi_{injo}, the average dc-link current will also get perturbed by a small amount ΔI_{dc} around its steady-state operating point I_{dco}

Hence, by substituting
$i_{inj} = i_{injo} + \Delta i_{inj}andI_{dc} = I_{dco} + \Delta I_{dc}$in equation (8), on neglecting the higher order terms

$$L_{dc}I_{dco}\frac{d}{dt}\Delta I_{dc} = 3\left(v_{sh}i_{injo} + v_{sh}\Delta i_{inj} - i_{injo}^2R_{sh} - 2i_{inj}\Delta i_{injo}R_{sh} - v_{sh}c_{sh}\frac{dv_{sh}}{dt}\right) \quad \ldots\ldots.. (9)$$

The steady-state equation can be written as

$$0 = 3\left(v_{sh}i_{injo} - i_{injo}^2R_{sh}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (10)$$

The linear relationship between Δi_{inj} and ΔI_{dc} can be obtained by subtracting (9) from (8)

$$L_{dc}I_{dc}\frac{d}{dt}\Delta I_{dc} = 3\left(v_{sh}\Delta i_{inj} - 2i_{injo}\Delta i_{inj}R_{sh} - v_{sh}c_{sh}\frac{dv_{sh}}{dt}\right) \quad \ldots\ldots\ldots\ldots (11)$$

The transfer function of the PWM converter for a particular operating point can be obtained from (12) as

$$K_c = \frac{\Delta I_{dc}}{\Delta i_{inj}} = 3\left(\frac{v_{sh} - c_{sh} v_{sh} s - 2 i_{injo} R_{sh}}{L_{dc} I_{dco} s}\right) \quad \text{…………………} (12)$$

The characteristic equation of the current control loop is used to obtain the constants of the PI regulator, which can be written as

$$1 + \left(k_p + \frac{k_i}{s}\right) 3\left(\frac{v_{sh} - c_{sh} v_{sh} s - 2 i_{injo} R_{sh}}{L_{dc} I_{dco} s}\right) = 0 \quad \text{……………………} (13)$$

The controller parameters are designed on the basis of 5% overshoot to step change in the amplitude of current reference. For the selected system with the following variables, a second-order characteristic equation is found for the closed-loop system

v_{sh} = 230 $volts I_{injo}$ = 5 $amp R_{sh}$ = 0.4Ω
c_{sh} = 24µ$F L_{dc}$ = 160 $mH I_{dco}$ = 5 amp

This characteristic equation is used to determine the components of the PI regulator. The analysis of this characteristic equation shows K_p that determines the current response and k_i defines the damping factor of the current loop. By substituting the values shown in (14), we obtain

$$1 + \left(K_p + \frac{K_i}{s}\right)\left(\frac{-0.0165s + 678}{0.8s}\right) = 0. \quad \text{……} (14)$$

$$0.8s^2 + k_p(678s - 0.0165s^2) + k_i(678 - 0.0165s) = 0 \quad \text{…. …...} (15)$$

Using Routh–Harwitz criteria for system stability, the limit of the stability region is found out for the characteristic equation shown in (15). The parameters of the PI regulator are obtained as K_p = 0.5 and K_i = 10. For the selected values of K_p and k_i in the most stable region.

4. DESIGN OF ANN CONTROLLER

Rapid detection of the disturbance signal with high accuracy, fast processing of the reference signal and high dynamic response of the controller are the prime requirements for desired compensation in case of UPQC. The conventional Controller fails to perform satisfactorily under parameter variations Nonlinearity load disturbance, etc. A recent study shows that NN-based controllers provide fast dynamic response while maintaining stability of the converter system over wide operating range. The ANN is made up of interconnecting artificial neurons. It resembles the brain in two aspects: 1) The knowledge is acquired by the network through the learning process and 2) Interneuron connection strengths are used to store the knowledge. ANNs are being used to solve problems without actually creating the dynamic system model. For improving the performance of a UPQC, a multilayer feed forward- Type ANN-based controller is designed.

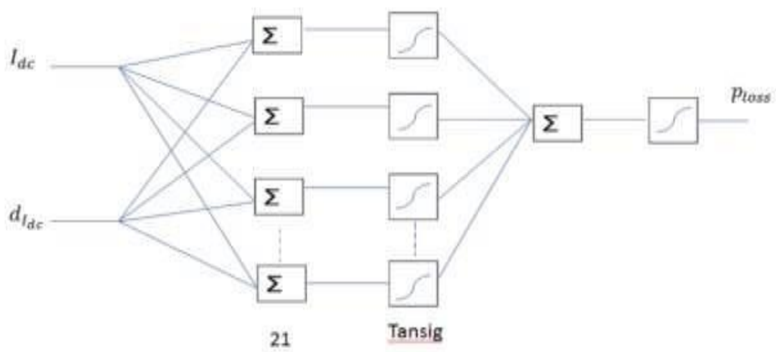

Fig. 4. Exploded diagram of artificial neural network

This network is designed with three layers, the input layer with 2, the hidden layer with 21, and the output layer with 1 neuron, respectively. The large data of the dc-link current for n and (n-1) intervals from the conventional method are collected and are stored in the Matlab workspace. This data is used for training the NN. The activation functions chosen are tan sigmoidal for input and hidden layers and pure linear in the output layer, respectively. This multilayer feed forward-type NN works as a compensation Signal generator. The network topology of the ANN is as shown in Fig. 4. The training algorithm used is Levenberg–Marquardt back propagation (LMBP). MATLAB programming of ANN training is given as follows**:**

net=New ff (minmax)(p),[2,21,1],{'tansig','tansig','purelin'},'trainlm');
net.trainParam.show=50;
net.trainParam.lr=0.05;
net.trainParam.lr_inc=1.9;
net.trainParam.lr_dec=0.15;

net.trainParam.epochs=1000;
net.trainParam.goal=1e-6;
[net,tr]=train(net,p,T);
a=sim(net,p); gensim(net,-1).

The compensator output depends on the input and its evolution. The NN is trained for outputting fundamental reference Currents. The signals thus obtained are compared in a hysteresis band current controller to provide switching signals. The block diagram of the ANN compensator is as shown in Figure 5.

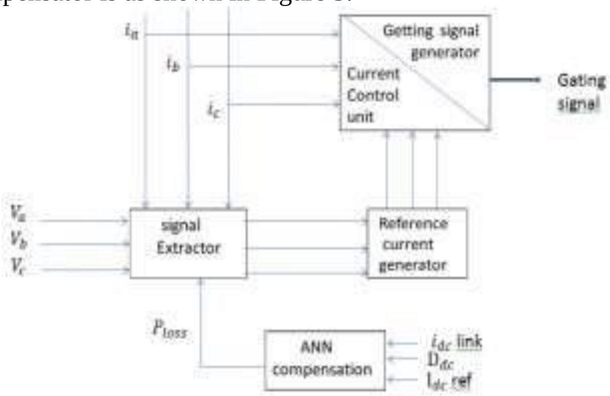

Fig. 5. Block diagram of the ANN-based compensator for offline training.

5. SIMULATION AND RESULTS

System used for study is shown in Figure 6. Two non-linear loads are connected to the system one operates continuously and the other is switched on in the system between 0.2 to 0.3 seconds. Source is 440V at 50Hz frequency.

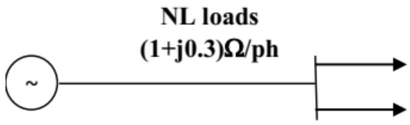

Fig.6. Single line diagram of the system under study

Two loading conditions are analysed for checking the effectiveness of given UPQC. Case1 is considered with loads of (50+j62.8), (80+j314) ohms. Performance is also checked with increased loading considerations as Case2 with both loads of values (1+j2) ohms. Performance of the system without UPQC is shown in Figure 7.

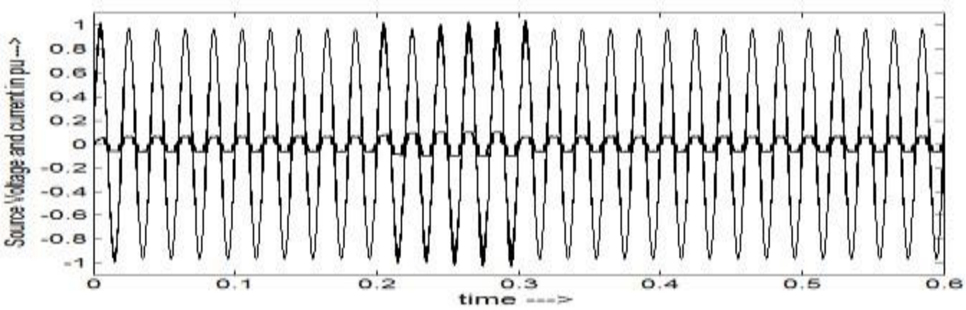

Fig 7. Performance of the system without UPQC

When the system is analysed for case 2, voltage sag is observed for Case2 which is as low as 0.25pu. Performance comparison is done with PI and ANN Controller sin controlling the dc-link current of designed UPQC. Performance of the Shunt active filter of the UPQC with the PI controller is given in Figures 8a and 8b while that with an ANN controller is given in Figures 9a and 9b.

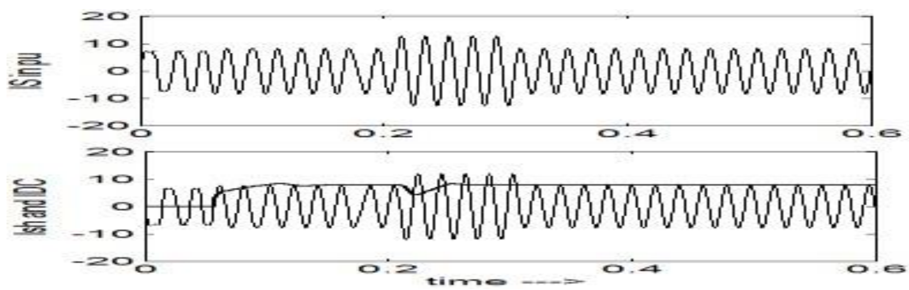

Fig .8a. Performance of UPQC with the PI controller Case1

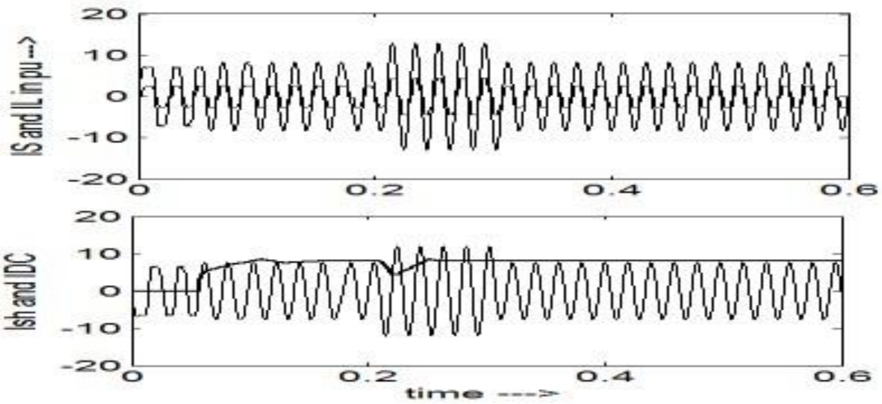

Fig .8b. Performance of UPQC with the PI controller Case2

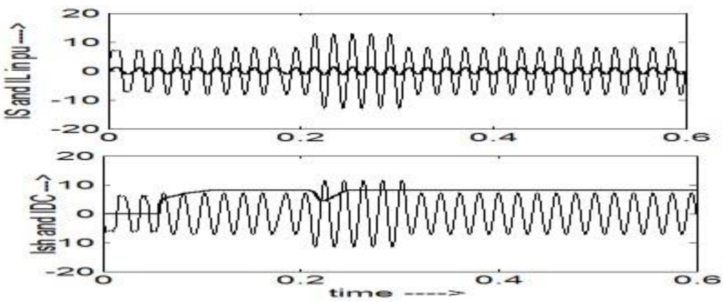

Fig. 9a. Performance of UPQC with ANN controller Case1

From Figures 8a and 8b it is observed that in case of the PI controller, the shunt filter takes almost twoand-a-half cycles to stabilize the dc-link current at the initial condition. At the instants if load changes it almost takes a similar amount of time to reach a stable state. In case of the ANN controller (Figures 9a and 9b), the dc-link current stabilizes within a half cycle after the start of theshunt filter, and at the load change, it takes almost one cycle to reach its mean value, thus improving system performance with ANN controller.

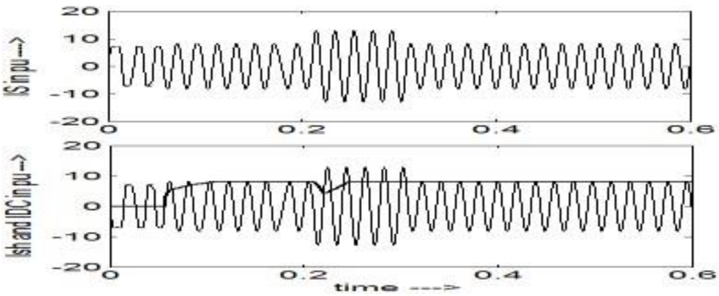

Fig. 9b. Performance of UPQC with ANN controller Case2

FFT analysis is carried out to get the frequency spectrum for the two loading cases 1 and 2. Source current and source voltage spectrums are studied for the system without UPQC, UPQC with PI and ANN controller. Values are tabulated in Table 1& Table 2. THD content of load voltages are found to be less than 0.30% with PI and ANN controllers.

Table 1 Total Harmonic Distortion (THD) evaluated from frequency spectrum

		% THD in Source Current	
	Time	Case 1	Case 2
Without UPQC	0.02	27.23%	--
	0.22	26.27%	--
	0.32	27.24%	--
With PI Controller	0.02	18.32%	18.32%
	0.22	0.78%	0.78%
	0.32	0.77%	0.77%
With ANN Controller	0.02	18.32%	18.32%
	0.22	0.68%	0.68%
	0.32	0.71%	0.71%

Table 2 Total Harmonic Distortion (THD) evaluated from frequency spectrum

		% THD in Source Voltage	
	Time	Case 1	Case 2
Without UPQC	0.02	8.65%	--
	0.22	9.33%	--
	0.32	8.59%	--
With PI & ANN Controllers	0.02	0%	0%
	0.22	0%	0%
	0.32	0%	0%

Source current is found to be content of all odd harmonic minus triplen, providing a total harmonic distortion (THD) of 27.23%. It is observed from PIcontrollerand ANN controller schemes source current and voltages have very low values of THD content and thus better wave form quality of both source voltages and currents with non-linear loads. From the THD values ANN has better performance than PI controller,thus improving system performance. Power factor of the system is automatically corrected to unity from 0.94 with PI and ANN controllers.

6. CONCLUSIONS

Performance of the UPQC mainly depends upon howaccurately and quickly reference signals are derived.Nature of the dc-link current in case of the PI and ANN control scheme are observed. It is observed that the power conditioner compensates for voltage as well as current harmonics. However, the performance of ANN controlleris proved to be better compared to conventional PI controllerin case of UPQC. Source Power factor is improved to Unity under highly loaded condition also for both PI and ANN controls. Finally, with ANN controller there is considerable improvement in the response time of dc-link current, which is the main concern in control of power quality in power system network.

7. SCOPE FOR FUTURE WORK

Proposed model for the UPQC is to compensate input voltage harmonics and current harmonics caused by non-linear load. The work can be extended to compensate the load voltage and load current imperfections. Proposed UPQC can be implemented using analog hardware, with the help of PLL and Hysteresis blocks.

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