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Improvement of Unified Power Quality Conditioner based on GA Optimized NN Controller

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ABSTRACT

The Power Quality has become one of the most significant problems for power electronics. Unified Power Quality Conditioner is one of the power electronics devices used for improving the power quality problems. During this problems the current across the dc-link is varied from the rated value. Dc-link current regulator is used to derive the actual reference signal from the distorted signal. In this paper, Genetic Algorithm (GA) optimized neural network is used to regulate the dc-link current and for current control of the active shunt filter instead of conventional controllers. The weight of the neural network changed during the training process so genetic algorithm is used for optimization. An exhaustive simulation study is carried out using matlab workspace to investigate the performance of the GA optimized NN controller and compare its performance with the conventional controller.

Keywords: Unified Power Quality Conditioner, Genetic Algorithm, Neural Network, Current source inverter, Voltage source inverter.

1. INTRODUCTION

Unified Power Quality Conditioner (UPQC, a combination of series and shunt power filters) is one of the custom power devices and compensates voltage and current quality problems. The UPQC consist of two voltage-source inverters or two current-source inverters that are connected to a DC energy storage device. One inverter is connected in series with the line while the other is connected in shunt [5]. It takes the advantages of series and shunt active power filters to compensate the unbalance of both source voltages and load currents. UPQC is used for harmonic removal and simultaneous compensation of voltage and current, and it enhances the power quality provided for other harmonic sensitive loads. The performance of UPQC mainly depends upon how accurately and quickly reference signals are derived[12]. 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, unified constant frequency (UCF) controllers, etc., are in use.Artificial-intelligence (AI) techniques, particularly the NNs, are having a significant impact on 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 PQ devices [3], [4], [10].

Also the weight of the network neuron may changed during the network training process; so the neural network (NN) training performance is affected[9]. To overcome this complexity, in this paper Genetic Algorithm (GA) based optimization algorithm is proposed for optimizing the output of NN and to design an optimized system for regulating the dc-link current of UPQC.

2. LITERATURE SURVEY:

Several research works related to UPQC are already available in the literature. A few literature works are reviewed here. K.R. Suja et.al [9], proposed a Unified Power Quality conditioner based on Genetic algorithm-neuro-fuzzy controller to reduce power quality problems. GA based optimization is used for optimizing the membership function of the fuzzy system. Here the voltage sag clearing time is 0.056 seconds.

Y.Hoseynpoor et.al [2], evaluated the joint operation of UPQC and distributed generation system with separated operation and compares these modes from economic point. The DG unit is assumed a wind energy conversion system (WECS). The VA rating of series and shunt inverters of UPQC are estimated for both coupled and decoupled systems. The active power of DG can flow to grid through the shunt inverter without any change in its capacity. The investment cost of coupled operation of UPQC with DG unit is significantly economic nearly 20%.

A. Jayalaxmi et.al [3], presented a compensation principle using PI and ANN control strategies of the Unified Shunt Series Compensator (USSC).The USSC is an active filter and it compensates the reactive power and harmonics in both voltage and current caused by load. It uses two back to back connected IGBT based Voltage Source Inverter with a common bus. ANN uses Levenberg Marquardt Back propagation (LMBP) Algorithm.

Othmane Abdelkhalik et.al[6], proposed an Adaptive Neuro Fuzzy system (ANFIS) is order to improve the performance of UPQC. In this method network neuron is used to optimize the membership function of the fuzzy controller.ie, ANFIS is an optimized FIS. Charging of DC link was too fast here and the THD was 3.96%. Also time taken for condensers voltage to reach the first overshoot is 0.025sec.

A. Zouidi et.al [14], proposed an artificial neural network (ANN) controller to control a three phase three wire voltage source active power filter instead of PI controller. The controller comprises of two three-layer feed forward ANN. This system has an advantage that it has only one storage device compared to three-phase four-wire system.

L. H. Tey et.al [10], used Linear Quadratic Regulator (LQR) control technique and hysteresis control technique in order to co-ordinate the operation of the series and shunt voltage source inverters of the UPQC and to generate accurate switching signals for the two VSIs respectively. The ANN controller is used with improved weights updating algorithm. Supply voltage harmonics, load current harmonics and power factor under balanced and unbalanced system operating conditions were compensated using this method.

R. El Shatshat et.al [8], proposed a current source converter topology based on intelligent control scheme for a modular single phase active power filter. The controller utilizes two adaptive linear neurons to process the signals obtained from power line. There is 50% reduction in the switching losses due to the incorporation of the 3-level PWM switching strategy. Higher order harmonics was suppressed and result in higher efficiency and better performance.

P. Jeno Paul et.al [4], developed a constant frequency unified power quality conditioner with fuzzy logic controller to maintain constant frequency in the utility. Frequency converter (matrix converter) used here is to regulate the supply frequency. Reactive power is maintained at minimum value. The matrix converter produced 60% of voltage harmonics and it is reduced at 1% by the proposed system. As the frequency increases from 60-65 Hz, the proposed system regulates the load frequency to a constant level.

3. CONFIGURATION

A conventional UPQC topology consists of the integration of two active power filters are connected back to back to a common dc-link bus. A simple block diagram of a typical UPQC is shown in Fig.1.

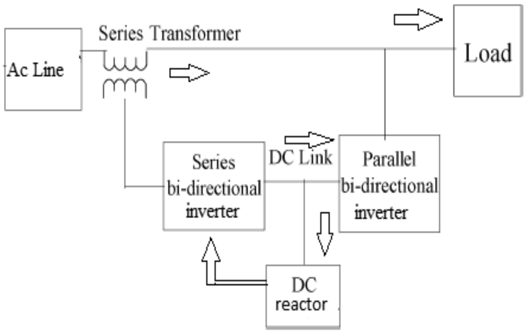

Fig.1. Block diagram of UPQC

It can be configured either with voltage-source converters or current source converters in single phase, three-phase three wire, or three-phase four-wire configurations. The UPQC with the voltage-source inverter (VSI) is most common because of its smaller size and low cost. But VSI has slow control of the converter (LC filter) output voltage and no short circuit/over current protection. The current source inverter (CSI)based UPQC has advantages of excellent current control capability, easy protection, and high reliability over voltage source inverter based UPQC [12]. The new insulated-gate bipolar transistors (IGBTs) with reverse blocking capability are being launched which are suitable for the CSI-based UPQC.

Current Source Inverter (CSI) is the device which converts AC to DC. In CSI the input behaves as a current source. The output current is maintained constant irrespective of load on the inverter and the output voltage is forced to change. Here two switches must always conduct- one from the upper side and one from the lower side switches. If two switches, one upper and one lower, conduct at a same time such that the output current is $\pm I_L$, the switch state is 1; whereas if these switches are off at the same time, the switch state is 0. The diodes in series with the switches are required to block the reverse voltages on the transistors. When two devices in different arms conduct, the source current I_L flows through the load. When two devices in different arms conduct, the source current is bypassed from the load. The load current can be expressed as

$$i_0 = \sum_{n=1,3,5....}^{\infty} \frac{4I_L}{n\pi} \sin\frac{n\delta}{2} \sin n\,(\omega t) \qquad 1$$

The performance of the UPQC mainly depends on how accurately and quickly the 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. A dc current regulator will serve as power-loss compensation in the filter circuits, which will take place through the activation of a shunt unit. This regulator will maintain dc-link current constant for stable operation of the filter. 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 dc-link value, is fed to the PI controller.

4.DESIGN OF CONTROLLERS:

The following equations are required to design the controller, since the dc-link current is controlled by the shunt filter.

$$i_s = i_L - i_{inj} \ldots\ldots\ldots\ldots\ldots\ldots.. \qquad (2)$$

$$i_{inj} = u_2 i_{dc} \ldots\ldots\ldots\ldots\ldots\ldots \qquad (3)$$

$$L_{sh}\frac{d_{inj}}{dt} = v_L - i_{inj}R_{sh} = v_L - v_{sh} \;\ldots\ldots \qquad (4)$$

In order to control the filter current (i_{inj}) the only control variable is the duty cycle of the PWM converter (u_2), 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. The energy transfer to the continuous side takes place only at the fundamental frequency to compensate all of the losses in the PWM converter. 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 compensation of the harmonic component. The value of i_{dc} needs to only be approximately constant and there is no dynamic performance to be attained. The more it is constant, the more linear the system will be. Hencei_{inj} is controlled indirectly by processing the actual source current and estimated reference current 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, PI controller is used in conventional methods. Mathematical model is required to design PI controller, since the dynamic response of the dc-link inductor has no effect on the compensation feature.The relation between the input (ac side) and output (dc-link side) quantities of the PWM converter are obtained by equating the rate of change of energy associated[12].

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

$$P_{ind} = \frac{d}{dt}\left(\frac{1}{2}L_{DC}I_{DC}^2\right) = L_{DC}I_{DC}\frac{dI_{DC}}{dt}\ldots.. \tag{5}$$

The power input to the PWM converter

$$P_{conv} = 3v_{sh}i_{inj}\ldots\ldots\ldots\ldots\ldots\ldots \tag{6}$$

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

$$P_{cap} = 3\frac{d}{dt}\left(\frac{1}{2}C_{sh}v_{sh}^2\right)\ldots\ldots\ldots \tag{7}$$

Power loss in the resistor

$$P_{loss} = 3i_{inj}^2R_{sh}\ldots\ldots\ldots\ldots \tag{8}$$

The characteristic equation of the current control loop is given as

$$1 + \left(k_p + \frac{k_i}{s}\right)\frac{3\left(v_{sh} - C_{sh}v_{sh}s - 2i_{inj0}R_{sh}\right)}{L_{dc}I_{dc}s} = 0 \tag{9}$$

Where, i_{inj0} is the small increment in the filter current.

4.1 Design of ANN controller:

The conventional controller fails to perform satisfactorily under parameter variations nonlinearity load disturbance, etc. The NN-based controllers provide fast dynamic response of the converter system over wide operating range.

Artificial Neural Networks (ANN) are non-linear information (signal) processing devices, which are built from interconnected elementary processing devices called neurons. An Artificial Neural Network is an information processing paradigm that is inspired by the way biological nervous systems, such as the brain process information. The key element of this paradigm is the novel structure of the information processing system. It is composed of a large number of highly interconnected processing elements (neurons) working union to solve specific problems. ANNs, like people, learn by example. An ANN is configured for a specific application, such as pattern recognition or data classification, through a learning process.

For improving the performance of a UPQC, a multilayer feedforward- type ANN-based controller is designed first. Artificial neural network consists of three groups, or layers, of units: a layer of "input" units is connected to a layer of "hidden" units, which is connected to a layer of "output" units as shown in the Fig. 4.

- The activity of the input units represents the raw information that is fed into the network.
- The activity of each hidden unit is determined by the activities of the input units and the weights on the connections between the input and the hidden units.

- The behaviour of the output units depends on the activity of the hidden units and the weights between the hidden and output units.

The input layer with 2, the hidden layer with 21, and the output layer with 1 neuron, respectively is developed for training the data. The large data of the dc-link current for and intervals from the conventional method are collected and are stored in the Matlab workspace. Using neural network fitting tool the network is trained based on the equations (8), (2) and (3). The activation functions chosen are tan sigmoidal for input and hidden layers and pure linear in the output layer, respectively. This multilayer feedforward-type NN works as a compensation signal generator. The network topology of the ANN is as shown in Fig.3.

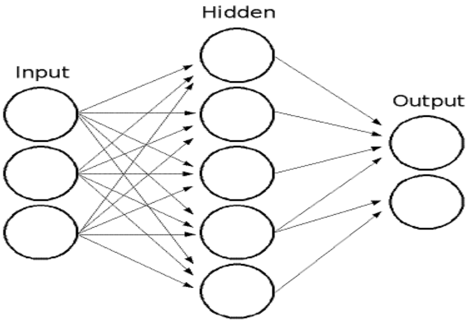

Fig.2. Neural network layers

The training algorithm used is Levenberg–Marquardt back propagation (LMBP). The output signal is optimized using genetic algorithm and provided as gating signal to the inverter and it depends on the input and its evolution. This gating signal is provided to the shunt CSI in order to regulate the dc-link current across the reactor.

4.2 GA optimized NN controller:

The output of the NN is optimized using the GA based optimization algorithm[9]. So, the complexity of UPQC controller is reduced and the DC-link current is regulated quickly. The steps required to optimize the NN output is given below:

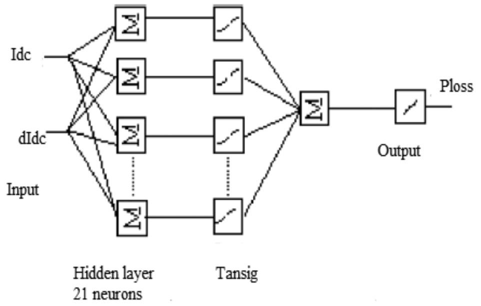

Fig.3. Exploded diagram of the artificial neural network

Step 1: Chromosome Generation

Generation of chromosomes is the first step in optimization. Random chromosomes are generated and they are considered as the initial chromosomes. Here, the error current (I) and change of error current (ΔI)are the target parameters of dc-link regulated current (I_{dc}). If the chromosome length $N_L = 2$, then the error voltage is chosen between the minimum and maximum values i.e., $y_{0(i)} \in [I^{min}, I^{max}]$ and $y_{1(i)} \in [\Delta I^{min}, \Delta I^{max}]$. From the error value, the respective optimized dc-link current is selected. This generation process is also called as initialization process. After generating chromosome, the next step is to calculate the fitness value for the generated chromosome.

Step 2: Fitness Function

Fitness function is one of the types of objective function, which is the leading target parameter to the optimized value. Here, the fitness function is used to determine the regulated dc-link current. The dc-link current (I_{DC}) is achieved by determining the reactor current (I_L). The fitness function is calculated by using the following formula.

$$V_c = \frac{1}{L} \int (I, \Delta I) \text{ ....} \tag{10}$$

The limit is given based on the dc-link reactor value. It is given in the range of 1 to 8amps. Using equation (10), the reactor voltage is calculated by the respective error and change of error current. From this value, the dc-link current is determined.

Step 3: Crossover

The crossover operation is performed between two chromosomes to obtain a new chromosome. 2000 chromosomes are taken for crossover. Based on crossover rate, the genes are selected and a new child chromosome is generated. After generating new chromosome, fitness function is applied to the new child chromosome.crossover rate is described as follows.

$$\text{Crossover Rate}(C_r) = \frac{\text{Number of Gene Crossovered}}{\text{Chromosome Length}}$$

Step 4: Mutation Operation

The mutation operation is done based on the mutation rate (M r). Here, the genes are mutated randomly based on the given mutation rate. The formula for calculating the mutation rate is given below.

$$\text{Mutation rate}(M_r) = \frac{M_P}{N_L}$$

where, $M_P$is the mutation point,

$N_L$is the chromosome length.

The population size (chromosome length) is taken as 50 and 500 generations are performed.

Step 5: Termination

In the termination stage, best chromosome is selected based on the fitness function. The above process is repeated until it reaches the maximum number of iterations.

After the completion of termination process, a possible set of error current, change of error current and the corresponding dc-link regulated current are obtained.

Using the optimized dc-link current output, dutycycle of the current source inverter is regulated. By this total harmonic distortion of UPQC has been reduced.

5.Results and Discussion:

The proposed GA optimized NN controller based UPQC is simulated in Matlab/Simulink platform. The performance of the UPQC is analyzed with THD problem. The simulink diagram of the UPQC with ANN controller and GA optimized NN controller is illustrated in Fig.4 and in Fig.5 respectively.

FFT window is considered for 20 cycles of the waveform and the FFT analysis is performed for both load current and load voltage waveforms. This is shown in Fig.9 and Fig.10. From this THD is calculated.

The comparison table shows that the load voltage harmonics have been reduced to 108.57 when GA optimized NN controller is used to regulate the dc-link current the UPQC.

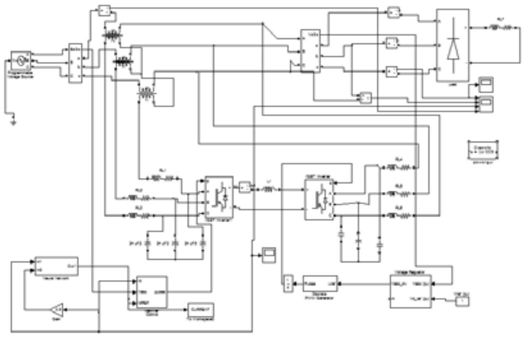

Fig.4 Simulation diagram of UPQC using ANN controller

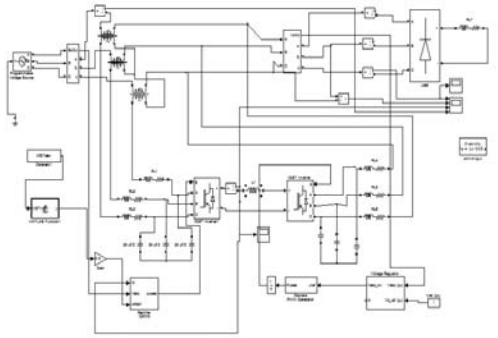

Fig. 5 Simulation diagram of UPQC using GA optimized ANN controller

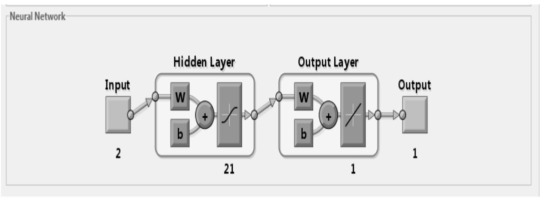

Fig.6 Neural network

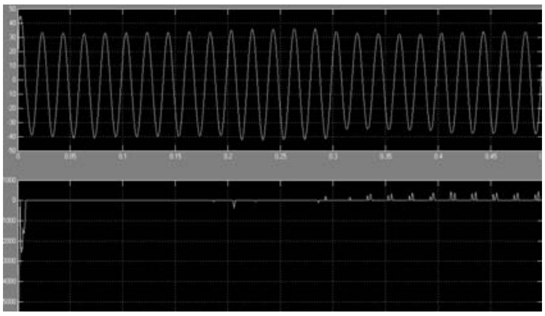

Fig.7 Load current and load voltage waveform using ANN controller

Fig.8 Load current and load voltage wave form using GA optimized NN controller

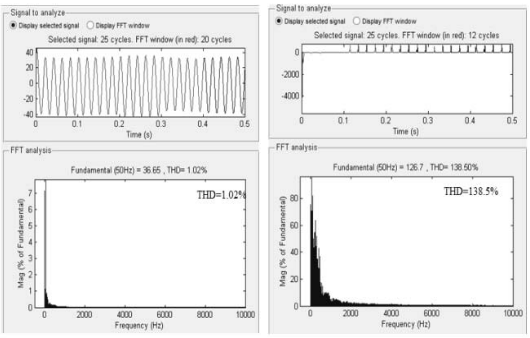

Fig.9 THD of UPQC using ANN controller

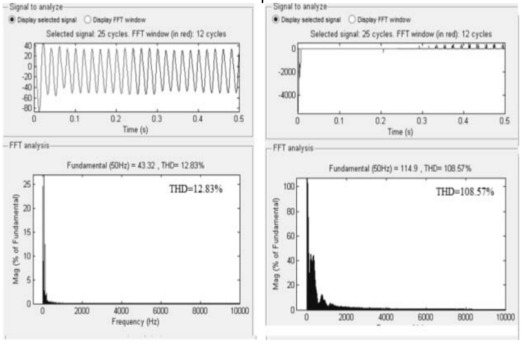

Fig.10 THD of UPQC using GA optimized NN controller

Table I: Comparison of controllers

Type of controller	PI controller	ANN controller	GA optimized NN controller
Load current harmonics	24.8	1.02	12.83
Load voltage harmonics	162.25	138.5	108.57

6. CONCLUSION

The performance of the UPQC mainly depends upon how accurately and quickly reference signals are derived. It was observed that the power conditioner compensates for voltage as well as current harmonics. However, its performance using the conventional PI controller and ANN controller has more THD in the load voltage waveform and it was not satisfactory, for obtaining satisfactory performance GA based NN controller is proposed, and its performance is analyzed by simulation. During the simulation study, the THD was reduced and it was low when compared with PI controller and ANN controller. In further other power quality problems can be considered and it can be analyzed by this methods.

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