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DESIGN OF UNIFIED POWER QUALITY CONDITIONER FOR IMPROVEMENT OF POWER QUALITY USING NEURAL NETWORK TOOLBOX

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Abstract— The electric power quality is affected by many factors like harmonic contamination, voltage instability, sag and swell due to the non-linear loads such as adjustable speed drives, switching of loads etc. The UPQC is an effective custom power device for the enhancement of power quality due to its quick response and high reliability. The UPQC can compensate these power quality problems. The control strategy used here are based on ANN controller of the UPQC with back propagation learning algorithm. An algorithm is also proposed to minimize the overall VA rating of UPQC which comparatively brings down the manufacturing cost. The harmonics are also reduced using the controller.The control strategy are modeled here using MATLAB / SIMULINK.

Keywords— Non-Linear load ,PQ, UPQC, Harmonics, VA Rating ,ANN ,Back Propagation

I.INTRODUCTION

In recent decades, power demand has increased tremendously while the expansion of power generation and transmission has been severely limited due to less availability of resources.As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system steady state control issues. Flexible AC transmission systems or FACTS are devices which allow the flexible and dynamic control of power systems. UPQC is one of the FACTS devices which are used here for the improvement of power quality [1],[9]and it has superior performance compared to other FACTS controllers despite of its high cost and complex structure.

Nowadays,the area of UPQC are directed towards operating the UPQC with minimum volt-ampere(VA) loading to reduce the manufacturing cost of the entire UPQC system and to reduce the overall losses by minimizing the harmonics there by increasing the power quality[2]. The UPQC system is designed in this paper considering the individual shunt and series inverter VA loadings under different operating conditions like steady state, voltage sag, voltage swell, and voltage and current harmonics compensation.

Power quality enhancement in Power Distribution system using artificial intelligence were proposed in several papers[3],[4],[5]. UPQC used to compensate input voltage harmonics and current harmonics caused by non-linear load. and power factor correction in a power distribution network using ANN with Hysteresis Control[3]. The Artificial Neural Network (ANN) controlled DVR is designed and the performance of the rectifier load connected system is investigated with the conventional ANN controller.The Levenberg- Marquardt (LV) Back propagation algorithm is used to implement the control scheme of the Voltage Source Inverter (VSI)[4].The problem of power quality of voltage sag is detected by artificial neural network then it is trained and the neural network output is simulated in neural network block set, then it will be removed using DSTATCOM with neural network control block. Different features or power line status were taken into account and simulated using Artificial Neural Network[5].

The main focus of this project is to simulate & design a UPQC system for improving the power quality by minimizing the VA Rating and the harmonics and by improving the voltage stability using an artificial neural network controller(ANN)[6]. Back propagation learning algorithm is used here which is a common method of training in artificial neural network which is used in conjunction with an optimization method and it takes less computational time. The ANN is trained to store solutions without excessive memory storage requirements. The control strategy are modeled here using MATLAB / SIMULINK.

II.Power Quality and its Problems

The power quality refers to maintaining a nearly sinusoidal bus distribution voltage at regulated magnitude and frequency[7]. Power quality determines the fitness of electrical power to consumer devices. The issue of electric power quality is achieving great importance because of many reasons like the society is becoming increasingly dependent on the electrical supply. New equipments are more prone to power quality variations.

Power quality problem can be defined as any problem disclosed in voltage, current or frequency deviation that leads to the failure of the customer equipment reveals itself as an economic difficulty to the user, or generates negative effect on the environment.The major types of power quality problems are:

- Interruption
- Voltage Sags.
- Voltage Swells
- WaveformDistortion
- Harmonics

III.Power Quality Improvement using UPQC

The power quality is an index to qualify of current and voltage available to industrial, commercial and household consumers of electricity. To eradicate this power quality issues, various devices are used such as Dynamic Voltage Restorer (DVR), Distributed Static Compensator (DSTATCOM),Static VAR Compensator (SVC) etc is used.Although all devices can improve the power quality,the UPQC is effective of all these FACTS devices. DSTATCOM, SVC etc provide shunt compensation only and TCSC, TCR, DVR etc provide series compensation only. But UPQC can provide both series and shunt compensation equally.

The UPQC is the the most advanced controlling FACT device over the all basic power system parameters that can compensate various voltage disturbances of the power supply,correction of voltage fluctuations and to hinder harmonic load current from entering into the power system[10]. It is a type of hybrid APF and is the only versatile device which can mitigate several power quality problems related with voltage and current simultaneously.It is also the combination of DSTATCOM and DVR,so it provide both series and shunt compensation simultaneously. The fundamental arrangement of UPQC is defined as there are two voltage source inverters which are connected through a common DC storage capacitor. First voltage source inverter is used in shunt with the transmission system with the help of shunt transformer. On the other hand second voltage source inverter is used in series with the help of series transformer**.** The shunt inverter provides VAR support to the load.Whenever the supply voltage undergoes sag then the series converter injects suitable voltage with supply..The DC Capacitor link allows bidirectional real power exchange between both inverters under steady state conditions. The schematic diagram of UPQC is shown in fig.1.

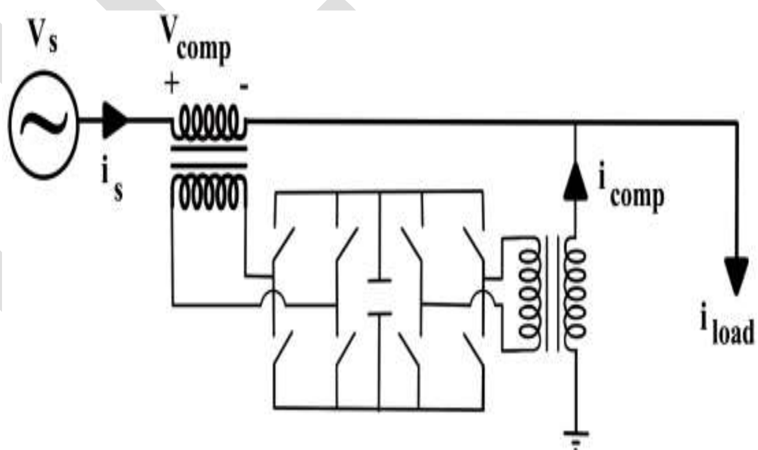

Fig.1:Schematic diagram of the unified power-quality conditioner (UPQC).

IV Artificial Neural Network

Artificial neural network are simplified model of the biological neuron system.It is a extensively parallel circulated processing system made up of highly interconnected neural computing elements that have the ability to learn and thereby acquire knowledge[8]. Their ease of use, inherent reliability and fault tolerance has made ANNs a viable medium for control..It possess information in parallel at high speed.Most important advantage compared to other controllers is its adaptability to new situations and it is trained to new frequencies.Back propagation algorithm is used here for the training.Other controllers like PI and PID Controllers need precise mathematical model for their analysis which is difficult to obtain under parameter variations and nonlinear load disturbances and another drawback of the system is that the proportional and integral gains are chosen experimentally.And the fuzzy controllers is based on rules and it is not adaptive to new situations[6].

Typical artificial neural network includes three layers:input layer, hidden layer and output layer. Fig 2 shows an ANN with hidden layer.

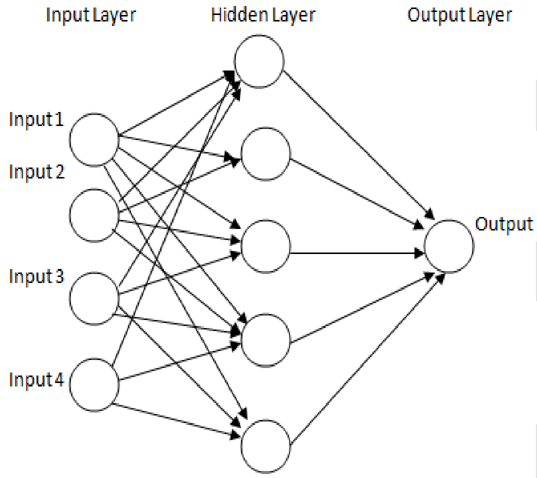

Fig 2: Artificial Neural Network Diagram

V.Neural Network Toolbox

The Neural Network toolbox is the proposed topology used here.Neural network toolbox in the MATLAB environment is one of the commonly used powerful,commercially and accurately available software tools for design of neural network.Neural network toolbox makes it easier to use neural networks in matlab software.The toolbox includes a set of functions and structures that handle neural network,so we do not need to write code for all activation function,training algorithms etc that we want to use. It can interface with other toolboxes also.It can support feedforward networks like perceptrons,radial basis network,back propogation,Hopfield etc.In this paper,enhancement of power quality using UPQC with the help of neural network tool box is proposed by minimizing the harmonics the VA rating and improving the voltage stability.

VI.Generalized Equations of UPQC for the proposed design for calculating the VA rating

The operation of UPQC with any arbitrary displacement angle between the source voltage (KV_S) and load voltage (V_L) under following condition are shown in the figure below, ie Steady state ($\kappa=1$), Voltage sag ($\kappa<1$), Voltage swell ($\kappa>1$) where κ is the Ratio between actual source and rated source voltages.

To keep the magnitudes of load voltage(V_L) and the displacement Angle(δ) constant, the voltage injected by the series Inverter (V_{se}) and its angle γ with source voltage (κV_s) are to be controlled according to the operating condition as shown in the figures 3,4 and 5.

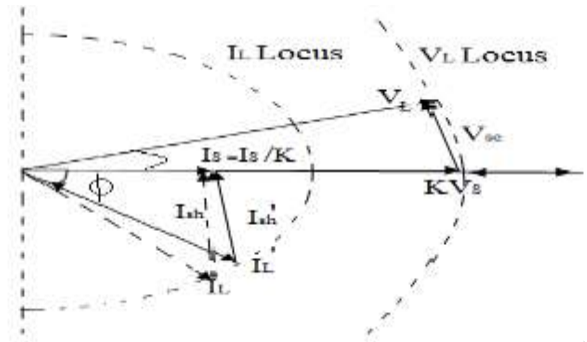

Fig.3 Operation of UPQC with displacement angle during steady state,k=1

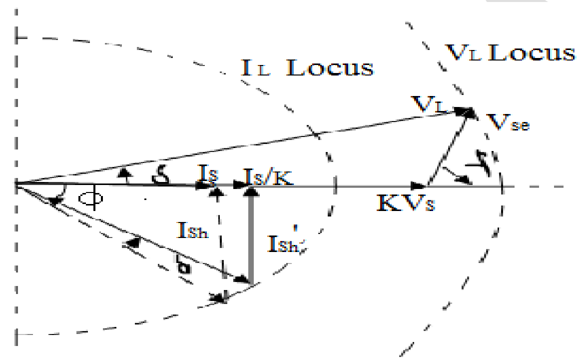

Fig4. Operation of UPQC with displacement angle during voltage sag

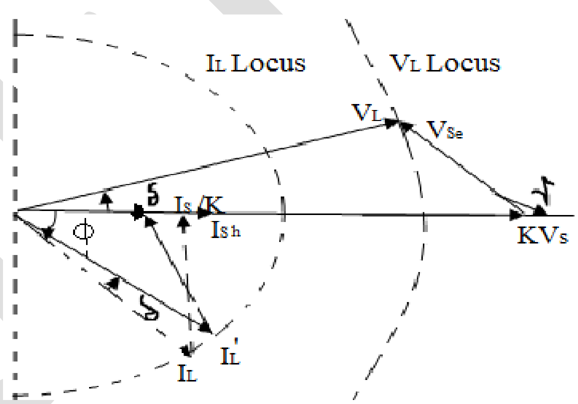

Fig5. Operation of UPQC with displacement angle during voltage swell, k>1

A. <u>VA Loading of the Series Part of UPQC</u>

The magnitude of injected series voltage can be written as:

$$V_{se}\left(\delta,k\right)=\sqrt{\left(V_L\cos\delta-kV_S\right)^2+\left(V_L\sin\delta\right)^2} \quad (1)$$

Where δ – Displacement angle between source and load voltages

The angle between the source voltage and injected voltage can be calculated as :

$$\gamma = 180^0 - \tan^{-1}\left[\frac{V_L \sin\delta}{kV_s - V_L\cos\delta}\right] if V_L \cos\delta \le kV_s \tag{2}$$

The active and reactive powers handled by the series inverter as a function of δ and κ are:

$$\mathbf{P}_{se}(\delta,\kappa)=V_{se}\times I_s/\kappa\times \mathrm{Cos}\gamma \tag{3}$$

$$Q_{se}(\delta,\kappa)=V_{se}\times I_s/\kappa\times \mathrm{Sin}\gamma \tag{4}$$

The VA loading of the series inverter at any operating condition is :

$$S_{se}(\delta,k) = \sqrt{\left(P_{se}(\delta,k)\right)^2 + \left(Q_{se}(\delta,k)\right)^2} \tag{5}$$

B. VA Loading of the Shunt Part of UPQC

The current injected by the shunt inverter can be calculated as:

$$I_{sh}' = \sqrt{\left(I_L' \cos(\phi-\delta) - \frac{I_S}{k}\right)^2 + \left(I_L' \sin(\phi-\delta)\right)^2} \tag{6}$$

where ϕ -Rated load power factor angle

In the above equation, $I_L' = I_L$ because maximum rms load current magnitude remains the same while the UPQC is in operation. The angle computed using the vector calculation is

$$\alpha = \tan^{-1}\left[\frac{I_L \cos(\phi-\delta) - \frac{I_S}{k}}{I_L \sin(\phi-\delta)}\right] \tag{7}$$

Using (3.18) and (3.19), the active and reactive powers handled by the shunt inverter are represented as:

$$\mathbf{P}_{sh}(\delta,\kappa)=V_L\times I_{sh}'\times \mathrm{Cos}[90-\delta+\alpha] \tag{8}$$

$$\mathbf{Q}_{sh}(\delta,\kappa)=V_L\times I_{sh}'\times \mathrm{Sin}[90-\delta+\alpha] \tag{9}$$

The VA loading of the shunt inverter at any operating condition is

$$S_{sh}(\delta,k) = \sqrt{\left(P_{sh}(\delta,k)\right)^2 + \left(Q_{sh}(\delta,k)\right)^2} \tag{10}$$

C. Total VA Loading of the UPQC

By adding (5) and (10), the total VA rating of UPQC as a function of δ and κ can be determined as:

$$S_{UPQC}=S_{sh}(\delta,\kappa)+S_{se}(\delta,\kappa) \tag{11}$$

Above equation represents the VA loading of any UPQC system for any given load during different operating conditions such as steady state (k=1), voltage sag(k<1), and voltage swell , (k>1.

In the proposed design method, [2]for every small step change (.01º) in δ the individual VA loadings of the series inverter,shunt inverter, and series transformer are computed under the full-load condition with: 1) $\kappa=1$; 2) $\kappa<1$; and3) $\kappa>1$ separately using (1)–(10). Then, it selects the maximum VA loading of the series inverter among the set of three values computed separately. This occurs simultaneously for shunt inverter VA loading, series-injected voltage, and the series transformer VA rating.These individual VA loadings/ ratings are stored in an array against the corresponding δ This process continues until the delta reach a value of 45º . The sum of the shunt inverter rating and series inverter rating , which represents the total VA rating of the UPQC, is then plotted against the angle stored in the same array. The valley point on the curve (A_{UPQC})is the minimum possible VA rating of the UPQC($S_{UPQC.}$) , and the corresponding is the optimum displacement angle between the source voltage and load voltage that guarantees minimum VA rating of the system. Once the optimum angle, δ is obtained, corresponding values are given as outputs from the data stored in internal memory. From Fig 6, the valley point on the total VA rating curve of UPQC is (15º, 5161 VA). The ratings of the series and shunt inverters corresponding to the minimum VA rating, using the proposed design method are: 2563 VA and 2598 VA, respectively. Hence, the total VA rating of the designed UPQC is 15483 VA[3(2563+2598)].

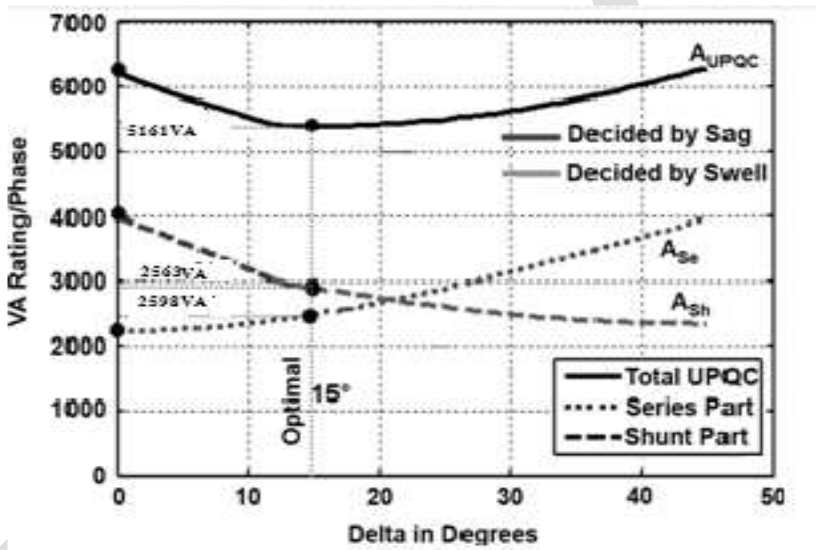

Fig 6: VA Rating Curve.

VII DESIGN OF UPQC WITH HARMONIC COMPENSATION

Another main focus of this paper is harmonic compensation using ANN Controller in the UPQC.Source voltage harmonics/unbalance can be mitigated by the series part of the UPQC only and current harmonics/unbalance can be tackled by the shunt part of the UPQC only[10]. Total Harmonic Distortion of source voltage(THD_v) and load current(THD_i) is found out using Fast Fourier Transform(FFT) analysis. THD of source voltage(THD_v) is 0.01% and load current is 0.44%.

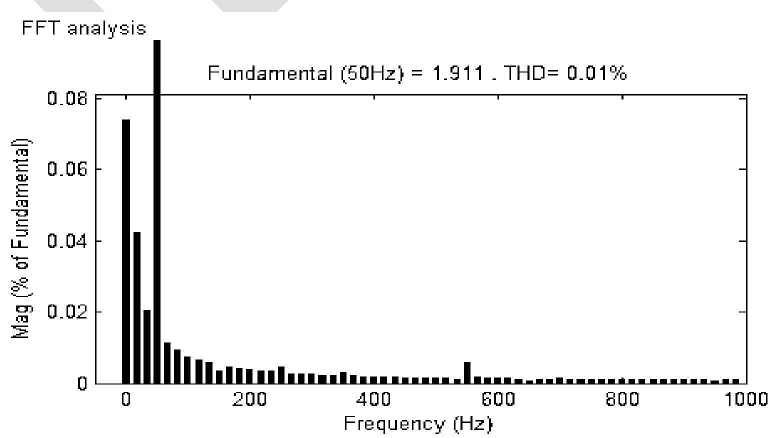

Fig7:THD of source voltage

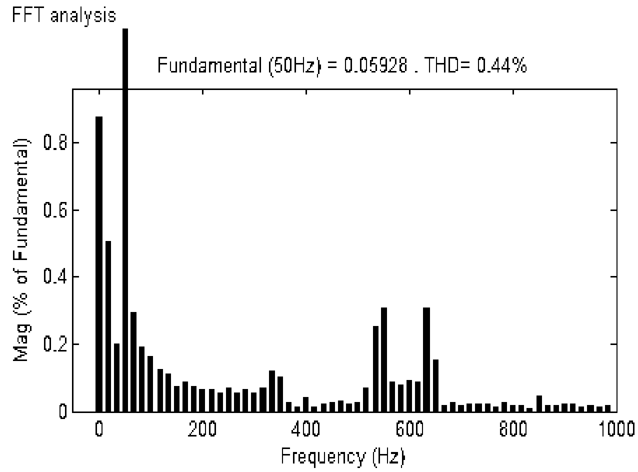

Fig 8.THD of load current

VII CONCLUSION

UPQC is designed with minimum VA rating and minimum harmonics.Generalized loading equations has been developed to identify the minimum possible VA rating of the UPQC system and that result in the calculation of corresponding optimal displacement angle, series inverter, shunt inverter, and series transformer ratings. This reduction in the VA rating of power-electronic converters comparatively brings down the manufacturing cost of the entire UPQC system. The harmonics produced in the system is reduced using the ANN Controller using back propagation learning algorithm and the THD is also calculated using the Fourier transform analysis.

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