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Evaluation of dynamic performance unified power quality conditioner controlled with various intelligent control schemes

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Power Quality (PQ) has become one of the major issues of concern for the distribution utilities. Custom power devices like power conditioners, Active Line controllers and reactive power compensator are gaining importance day by day in maintaining PQ Standards. The reliability of any PQ conditioning devices depends on the quality of control method used. This paper mainly focuses on comparison of dynamic response of a Unified Power Quality Conditioner (UPQC) for current harmonic elimination in a distribution system when controlled with a Fuzzy Logic Controller (FLC), Artificial Neural Network based Controller and Adaptive Neuro Fuzzy Controller. The fundamental and harmonic components of supply currents are extracted using an extended Phase Locked Loop (EPLL). The UPQC is realized with the help two back to back connected Voltage Source Converters (VSC). Simulation results prove the effectiveness of the control schemes when the load is non-linear in nature. Simulation results presented depict the dynamic performance of the system under study in steady state conditions.

Key *words: Unified Power Quality Conditioner (UPQC), Dynamic performance, Fuzzy Logic Controller, Adaptive Neuro-Fuzzy Inference System (ANFIS), Power Quality (PQ), Voltage Sag / Swell, Current Harmonics.*

1.0 INTRODUCTION

Power Quality (PQ) problems have been exists in power system utility for many years, but from past two decades they have become a major issue of concern. This is mainly due to the increased usage of solid state and power electronic devices. But this PQ problem represents a huge cost to business in lost productivity and equipment damage. Utilities and customers are spending huge amounts of money for monitor, study and for improvement of PQ.

The Unified Power Quality Conditioner (UPQC) is one of the best custom power devices used for compensation of PQ issues related to distortions in both source and load voltages as well currents. UPQC consists of a series and shunt Active Power Filters (APFs) connected with a common DC link [1].

The shunt APF is used to compensate current harmonic components [2, 3, 4]; unbalance and reactive power components [5] present in load current and also prevents the power system from the undesired effects caused by these distortions. By exchanging the active power with the system the Shunt APF will compensate the DC voltage and a constant DC voltage is restored. Proper compensation for any particular PQ issue can be provided if the issue related to PQ is detected or diagnosed properly. Identifying the harmonic currents of the load current is the most important in the control structure Shunt APF for harmonic current compensation and identifying correct level Sag / Swell or harmonic or sub-

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harmonic components in supply voltages in the control structure of series APF.

Control strategies such as instantaneous power theory (p-q theory), Synchronous reference frame (SRF) control strategy assume that the distortion in load currents and voltages are equal in all three phases. But in most of the practical cases this assumption doesn't suit. Some of the control strategies have limited application and are too complicated to implement. Frequency domain based approaches like Fast Fourier Transform can extract distortions of load currents and supply voltages accurately but provides accurate values in steady state conditions only and response includes delay also.

The performance of UPQC mainly depends upon how accurately and quickly the reference signals are derived. Control approaches based on PI, PID require precise linear mathematical models, which were difficult to obtain and may fail to perform satisfactorily under parameter variations, load disturbance etc.

Number of unconventional techniques evolved in recent days, compared to conventional converters these unconventional converters can learn, remember and make decisions. Control techniques based on Fuzzy Logic, Neural Networks and Adaptive neural techniques have significant impact on power electronic applications.

Any comprehensive control strategy used for control of UPQC must be simple, accurate, and faster in estimating amplitude; phase angle should have the capability of extracting voltage and current distortions accurately.

This paper mainly emphasizes in evaluation of dynamic response of UPQC for stabilizing the DC – Link voltage using FLC, ANN Controller and ANFIS of based control schemes. System Configuration is described in Section II, UPQC Control System is presented in Section III, Control of DC Voltage using control techniques based on Fuzzy logic rules, ANN and Adaptive Neuro – Fuzzy Control scheme are presented in section IV,. Simulation results are presented in Section V.

2.0 SYSTEM CONFIGURATION

Conventional UPQC consists of integration of series active power Filter (SeAPF) and Shunt Active Power Filter (ShAPF), connected back to back to a common dc – link bus [6]. Block diagram of UPQC is presented in Figure 1. Configuration of UPQC using two Voltage source converters connected back to back through a large capacitance is shown in Figure 2.

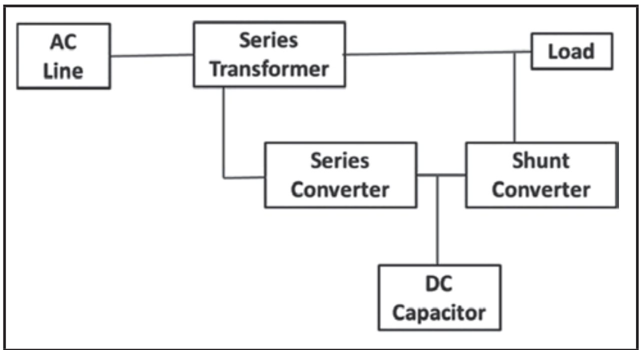

FIG. 1: BLOCK DIAGRAM OF UPQC

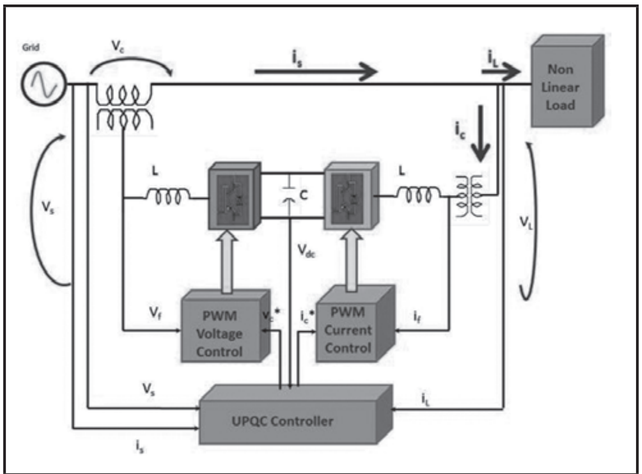

FIG. 2: UPQC USING VOLATGE SOURCE CONVERTERS

The performance of UPQC mainly depends upon how accurately and quickly the reference signals are derived. After effective extraction of the disturbance or distortions from the signal, suitable dc – link voltage regulator is used for derivation of actual reference signals. This DC voltage regulator serves as power-loss compensator in the filter circuit. The regulator will maintain a constant magnitude in order to maintain a stable operation of UPQC. In general the actual dc-link voltage and reference value is fed to the controller. The output of the controller is added suitable for generation of reference template.

3.0 UPQC CONTROL SYSTEM

UPQC has the ability of improving the PQ issues mainly by compensating current harmonics, voltage sag / swell, flicker and voltage harmonics. The control system of UPQC can be divided into three parts. 1. Series APF control 2. Shunt APF Control and 3. DC link balance.

The main objective of Series APF is to mitigate voltage related issues and Shunt APF is to mitigate current related issues. The DC balance is used for attaining power balance between the filters. In general capacitor is used as a DC link for maintaining power balance between the converters.

Schematic diagram of UPQC used for voltage sag / swell, harmonic and current harmonic compensation is shown in Figure 2.

The UPQC control scheme that designed for mitigation of power quality issues should be capable of identifying the fundamental and harmonic components and / or positive, negative and zero sequence components. In general Phase Locked Loops are used for extraction of frequency, amplitude and phase angle of voltages and currents are used. This paper uses Extended Phase Locked Loop (EPLL) proposed in [16]. The fundamental objective of any Phase Locked Loop is to provide an accurate estimation of grid voltage, frequency and phase even in the presence of harmonic components, positive and negative sequences and dc offset. The PLL used in this paper provides fast settling time.

4.0 CONTROL OF DC VOLTAGE

It is necessary to determine the DC – link voltage before selecting the DC link Capacitor C_{dc}. The DC link voltage selected is slightly higher than the peak to peak value of the phase voltage to ensure proper compensation by the ShAPF. There were no particular constraints on selecting the DC-link voltage, if low value of DC voltage

is selected the harmonic performance would be degraded. By taking the DC Capacitance to be large enough to suppress the voltage fluctuations on the DC –link under load variations.

A. Fuzzy Logic Controller

Fuzzy logic is based control is a kind of heuristic control approach. Fuzzy logic provides a formal methodology for representation, manipulation and implementation of human's experience based knowledge to control the system. Fuzzy logic uses human expertise and knowledge to deal with uncertainties in the control process.

FLC block diagram is shown in Figure 3. The FLC divided into four main parts (i) Fuzzification (ii) Rule base (iii) Inference mechanism (iv) Defuzzification.

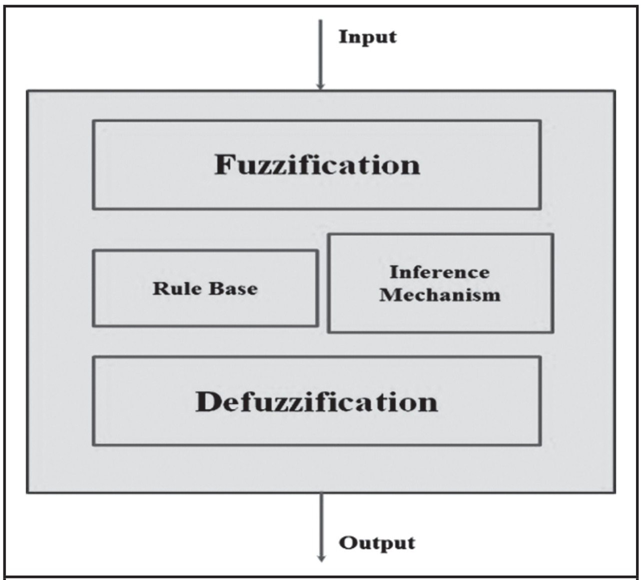

FIG. 3: BLOCK DIAGRAM OF FUZZY CONTROLLER

The effectiveness of FLC depends on the nonlinear mapping of input-output relation and the fuzzy partition over output space. Tuning of membership is more crucial in implementation of FLC.

For the present problem the two inputs that were taken for the FLC are Error (*e*) in capacitor voltage and change error or capacitor voltage (Δe). The scale over which membership functions described are [-1 1] and the output variable is the power loss in p.u. 11 different fuzzy Membership functions are defined over the interval [-1 1] for the input and output variables for the purpose of control design and is presented in Table – 1.

TABLE 1

DIFFERENT TYPES OF MEMBERSHIP FUNCTIONS DEFINED FOR INPUT AND OUTPUT VARIABLES.

S. No	Membership Function	Short From	Type of Membership
1	**N**egative **V**ery **B**ig	**NVB**	Gaussian
2	**N**egative **B**ig	**NB**	Gaussian
3	**N**egative **M**edium	**NM**	Gaussian
4	**N**egative **S**mall	**NS**	Gaussian
5	**N**egative **V**ery **S**mall	**NVS**	Gaussian
6	**Z**ero **E**rror	ZE	Gaussian
7	**P**ositive **V**ery **S**mall	**PVS**	Gaussian
8	**P**ositive **S**mall	PS	Gaussian
9	**P**ositive **M**edium	**PM**	Gaussian
10	**P**ositive **B**ig	PB	Gaussian
11	**P**ositive **V**ery **B**ig	**PVB**	Gaussian

B. Artificial Neural Network Based Controller

ANN based controllers provide fast dynamic response while maintaining stability of the converter system over a wide range of operating conditions. An ANN interconnection of several processing units popularly called as artificial neurons. In an ANN the neurons are interconnected in such a manner they attain the ability of learning and adaptability. Any ANN resembles human brain in two aspects (i) Acquiring knowledge from the outside environment (ii) storing and processing of information. The ANNs are characterized by their topology, the manner in which communication is made with the environment, the way how they are trained and their ability to process the information. ANN does not require a model creation for its implementation.

For the improvement of dynamic response of a UPQC a multilayer feed forward type ANN based controlled is used. Any multilayer feed forward ANN contains 3 layers namely input layer, hidden layer and output layer. Controller for DC-link voltage balancing is designed as multi input single output type with 2 neurons in the input layer, 50 neurons in the hidden layer and 1 neuron in the output layer. The neural network thus designed is trained with the test data for number of times with the help of Function Fitting tool of ANN toolbox of MATLAB. The Lavenberg-Marquardt Back propagation algorithm is used for weight optimization. The output of the ANN is the estimated power loss in p.u of the system. Architecture of ANN used for training purpose is shown in Figure 4. For hidden layer symmetric sigmoid and for output Layer Linear transfer functions are used as activation functions.

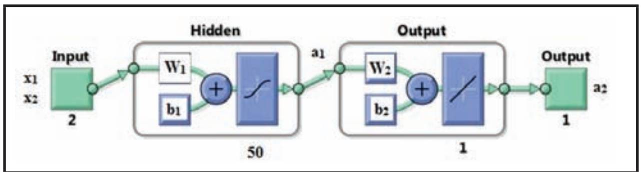

FIG. 4: ARCHITECTURE OF ANN USED FOR TRAINING

The input output relations of input and hidden layers are given by

$$a_1 = \tan sig(W_1 x + b_1)$$
$$a_2 = purelin(W_2 a_1 + b_2)$$

ANN based DC voltage balancing circuit modeled using MATLAB SIMULINK is shown in Figure 5.

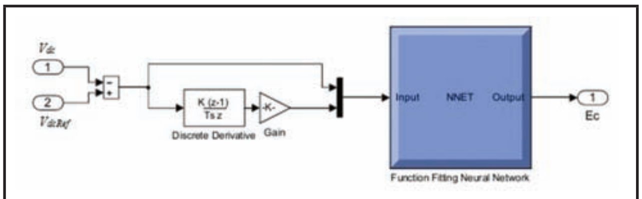

FIG. 5: ANN BASED CONTROL CIRCUIT FOR DC VOLTAGE BALANCING

C. Adaptive Neuro – Fuzzy Based Controller

Neural networks gained popularity in pattern recognition, classification. But it would be a typical task to explain how they reach their level cognitive features in decision making, deals the issues decisions. Fuzzy logic has the ability of providing high- as approximate reasoning and natural language processing. Neural networks and fuzzy logic can be treated complementary to each other; combinational implementation of both provides benefits of both the techniques. When they combined and used in decision making they make an adaptive network most popularly known as Adaptive neuro Fuzzy Inference System (ANFIS).

The structure of ANFIS with 2 inputs, five membership functions, and 25 rules is shown in Figure 6. First order Sugeno type fuzzy system is used for the ANFIS Controller [16].

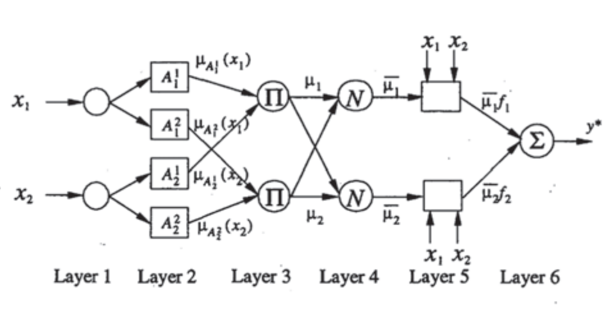

FIG. 6: ARCHITECTURE OF ANFIS CONTROLLER

ANFIS system shown in Figure 6 contains 6 Layers, The Layer 1 is associated with the inputs, and the inputs taken for analysis are error and change in error of capacitor voltage. This layer is most popularly known as input layer. This layer passes external signals to the next layer.

Layer 2 is known as implication layer, each node in this layer acts as a membership function, and its output

specify the degree to which a given input satisfies the quantifier. Continuous and piece – wise differentiable functions are used as node functions in this layer. Parameters of this layer are known as precondition parameters.

The output of nodes if layer 3 is the products of their input signals. Each node present in this layer describes the firing strength of each rule. T-norm operators are used as node functions for the generalized AND Function.

In Layer 4 the weights of all the inputs are normalized and all the nodes in this layer are fixed. This layer is known as normalized layer. The output of each node present in this layer gives the normalized firing strength.

Layer 5 is defuzzifying layer; each node present in this layer is adaptive one. Every node of this layer evaluates the weighted consequent value. Parameters of this layer are referred as consequent parameters.

Layer 6 is output layer; the output of this layer is summation of all input signals.

The ANFIS system architecture that was shown in Figure 6 uses back – propagation algorithm for updating the parameters.

5.0 SIMULATION RESULTS

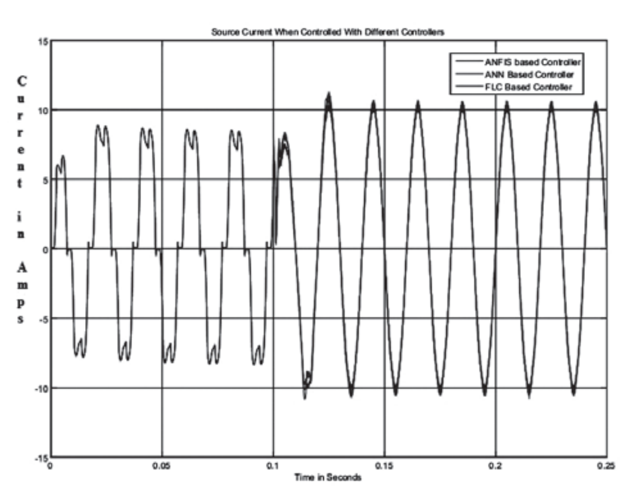

FIG. 7: SOURCE CURRENT WITH UPQC IN AMPS

A MATLAB / SIMULINK based model of UPQC is developed and tested under distorted and balanced AC mains to validated the proposed different control schemes. A non-linear load with 22.24% is connected to the AC mains with power rating equal to 20KVA. Performance of the control is validated in the time domain and analysed using Voltage Source Converter based SeAPF and ShAPF with non-linear load. The Total

Harmonic Distortion (THD) in source current and Voltage is analysed with UPQC When UPQC is controlled with FLC, ANN and ANFIS based control schemes. The Source current, load voltages and DC-link Voltage are presented in Figures 7 to Figure 9 When UPQC is controlled with ANFIS, ANN and FLC based Controllers respectively. The total harmonic distortion in supply current and source voltages are presented in Table – 2, When UPQC is controlled with ANFIS, ANN and FLC based Controllers.

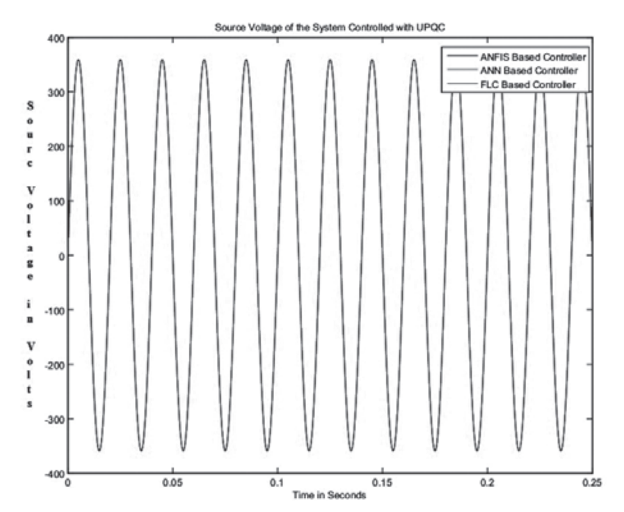

FIG. 8: SOURCE VOLTAGE WITH UPQC IN VOLTS

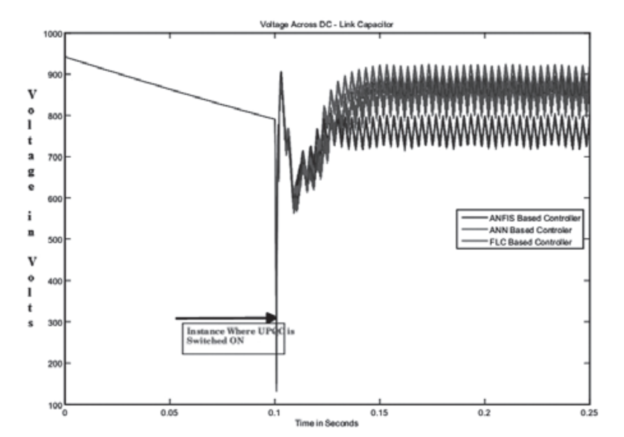

FIG. 9: DC-LINK VOLTAGE IN VOLTS

TABLE 2 THD CONTENT PRESENT IN SUPPLY VOLTAGE AND			
S. NO	CONTROLLER	% THD IN	% THD IN SUPPLY
	Used	*Supply Voltage*	*Current*
1	FLC	0.84	2.65
2	ANN	1.72	2.01
3	ANFIS	0.72	1.87

6.0 CONCLUSION

The dynamic response of UPQC controlled with the different controllers for DC-link voltage stabilization is performed using MATLAB, Sim Power Systems Toolbox. The system under investigation is modelled and the FLC and ANFIS are designed using Fuzzy Logic Toolbox and ANN controller is trained with the help of Neural Network toolbox. From the simulation results was found that the total harmonic distortion in the source current is found to be 2.65%, 2.01% and 1.87% and in supply voltage the THD is found as 0.84%, 1.72% and 0.72% when Controlled with FLC, ANN and ANFIS based Controllers respectively. The results presented depict that with the ANFIS based controller the system achieves better dynamic response in comparison with FLC and ANN based controllers. The principal advantage intelligent controllers is that they do not require any separate model for their implementation and provide best heuristic approach for problem solving.

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