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Comparison of Different Controllers on Unified Power Quality Conditioner

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Abstract —*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 APF also acts as a power-conditioning device which provides a cluster of multiple functions, such as harmonic filtering, damping, isolation and termination, load balancing, reactive-power control for power-factor correction and voltage regulation, voltage-flicker reduction, and/or their combinations. The custom power devices using these active power filters are playing a major role in compensating the power quality problems in the distribution systems. The Recent research focuses on use of the unified power quality conditioner .In this paper, three controllers PI, ANN and Fuzzy logic controllers are proposed for the current control of shunt active power filter and ANN and Fuzzy are developed using the data from conventional PI controller. The performances of all the controllers are compared by using simulation studies conducted in MATLAB-SIMULINK.*

Keywords**—** *Artificial intelligence (AI), artificial neural network (ANN), CSI, Fuzzy controller, Proportional integral (PI), Unified Power-Quality Conditioner (UPQC)*

I. INTRODUCTION

The use of electronic controllers in the electric power-supply system has become very common. These electronic controllers behave as nonlinear load and cause serious distortion in the distribution system and introduce unwanted harmonics in the supply system, leading to decreased efficiency of the power system network and equipment connected in the network [2]. To meet the requirements of harmonic regulation, passive and active power filters are being used in combination with the conventional converters [3]. 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 APF also acts as a power-conditioning device which provides a cluster of multiple functions, such as harmonic filtering, damping, isolation and termination, load balancing, reactive-power control for power-factor correction and voltage regulation, voltage-flicker reduction, and/or their combinations. Resent research focuses on use of the universal power quality conditioner (UPQC) to compensate for 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, sliding-mode, predictive, unified constant frequency (UCF) controllers, etc., are in use [6]-[8]. 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 variation nonlinearity load disturbance, etc.

Modern control theory-based controllers are state feedback controllers, self-tuning controllers, and model reference adaptive controllers, etc. These controllers also need mathematical models and are therefore sensitive to parameter variations. In recent years, a major effort has been underway to develop new and unconventional control techniques that can often augment or replace conventional control techniques. A number of unconventional control techniques have evolved, offering solutions to many difficult control problems in industry and manufacturing sectors. Unlike their conventional counterparts, these unconventional controllers (intelligent controllers) can learn, remember, and make decisions. 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. 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. On the other hand, the fuzzy-logic based controllers are also used for the control circuit design of UPQCs. In this paper, for improving the performance of a UPQC, a multilayer feed forward-type ANN-based controller, fuzzy logic based controller are designed for the current control of the shunt active filter instead of the conventional PI controller. The two controllers are designed based on the data from the conventional PI controller. Various simulation results are presented and verified experimentally.

II. CONFIGURATION OF UPQC

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.

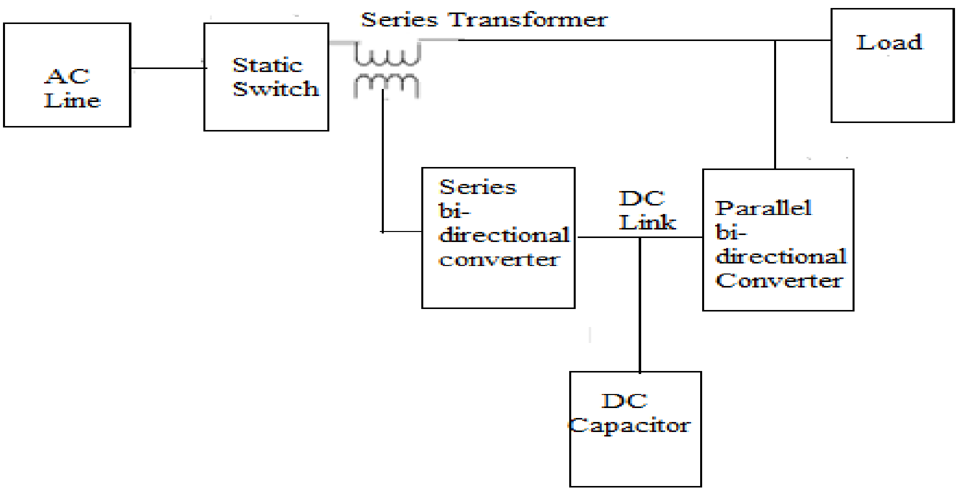


Fig.1 Block diagram of a UPQC.

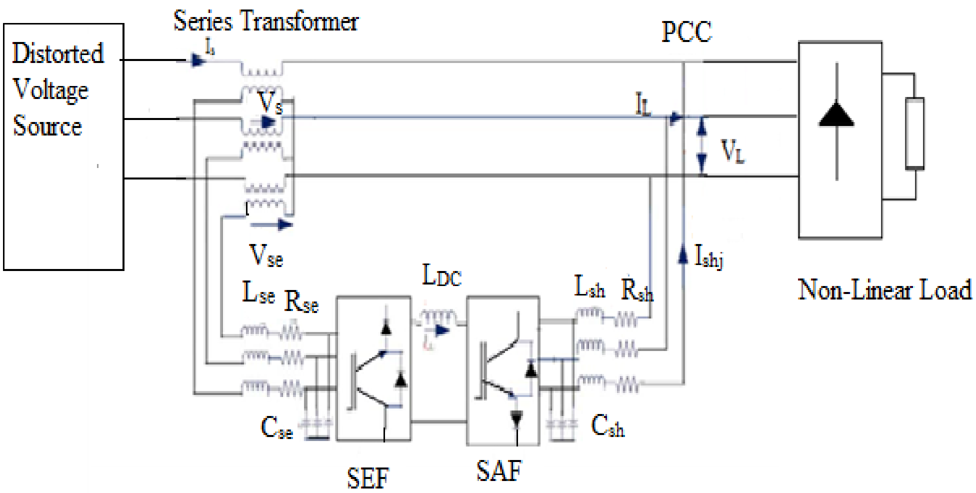


Fig.2 UPQC topology using current-source converters

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 converter (VSC) is most common because of its smaller size and low cost. Despite these previously mentioned advantages, the VSI topology has slow control of the converter (LC filter) output voltage and no short-circuit/over current protection. When the active rectifier inside the 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 CSI-based 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 SMES coils, the size and losses can be reduced considerably. A configuration of UPQC using two current-source converters connected back to back through a large dc-link reactor is shown.

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. The output of the PI controller is added suitably for the generation of a reference template [1].

III. DESIGN OF PI CONTROLLER

The design of PI controller for current source inverter is done by the following assumptions [1]

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 inductor.
4) Ripples in the dc-link current are neglected.

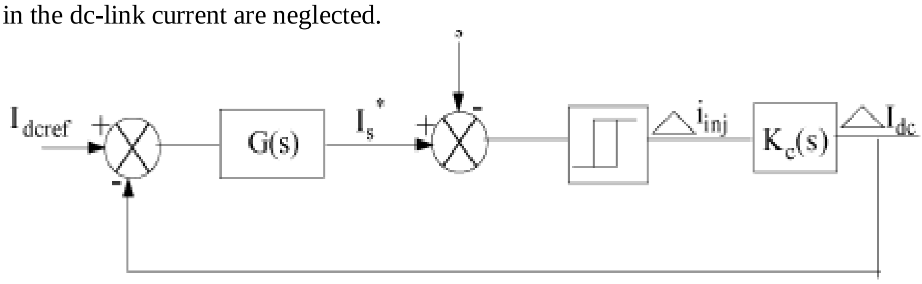


Fig.3 Block diagram of the current control loop.

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

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

The power input to the PWM converter

$$P_{conv} = 3V_{SH} \; I_{inj} \quad (2)$$

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

$$P_{cap} = \frac{d}{dt}\left(\frac{1}{2} C_{SH} V_{SH}^2\right) \quad (3)$$

Power loss in the resistor

$$P_{loss} = 3{I_{inj}}^2 R_{SH} \quad (4)$$

Equating them

$$P_{ind} = P_{conv} - P_{loss} - P_{cap} \quad (5)$$

Substituting the values

$$L_{dc} I_{dc} \frac{dI_{dc}}{dt} = 3(V_{SH} \; I_{inj} - {I_{inj}}^2 R_{SH} - C_{SH} V_{SH}^2 \frac{dV_{SH}}{dt}) \quad (6)$$

In order to linearize the power equation, a small perturbation ΔIinj is applied in the input current Iinj of converter about a steady-state operating point Iinjo, the average dc-link current will also get perturbed by a small amount ΔIdc around its steady-state operating point Idco

$$I_{inj} = I_{injo} + \Delta I_{inj} \quad \text{and} \quad I_{dc} = I_{dco} + \Delta I_{dc} \quad (7)$$

In (6) neglecting higher order terms

$$L_{dc} I_{dco} \frac{d\Delta I_{dc}}{dt} = \left(V_{SH} \; I_{injo} + V_{SH} \; \Delta I_{inj} - {I_{injo}}^2 R_{SH} - 2I_{inj} \Delta I_{inj} R_{SH} - C_{SH} V_{SH} \; \frac{dV_{SH}}{dt}\right) \quad (8)$$

Subtracting (4.8) from (4.6)

$$L_{dc} I_{dc} \frac{d\Delta I_{dc}}{dt} = 3(V_{SH} \; \Delta I_{inj} - 2I_{inj} \Delta I_{inj} R_{SH} - C_{SH} V_{SH} \; \frac{dV_{SH}}{dt} \quad (9)$$

The transfer function of the PWM converter for a particular operating point

$$\mathrm{Kc} = \frac{\Delta \mathrm{Idc}}{\Delta \mathrm{Iinj}} = 3\left(\frac{V_{SH} \quad -C_{SH}\, V_{SH} \quad s - 2I_{injo}\, R_{SH}}{L_{dc}\ I_{dco} \quad s}\right) \tag{10}$$

The characteristic equation of Pi controller is

$$1 + \left(\mathrm{Kp} + \frac{\mathrm{Ki}}{\mathrm{S}}\right) 3\left(\frac{V_{SH} \quad - C_{SH}\, V_{SH} \quad s - 2I_{injo}\, R_{SH}}{L_{dc}\ I_{dco} \quad s}\right) = 0$$

Some of the parameters are taken from [1] as

V_{sh}=230V, Iinjo=5 amp, R_{sh}=0.4Ω, C_{sh}=24μF, L_{dc}=160mH, I_{dco}=5 amp

Hence the characteristic equation on substitution of the values is

$$0.8s^2 + \mathrm{kp}(678 - 0.0165s^2) + \mathrm{Ki}(678 - 0.0165s) \tag{11}$$

Using Routh Harwitz criteria the values of Kp=0.5 and Ki=10 are chosen for the PI controller that is used in UPQC

IV. DESIGN OF ANN CONTROLLER

The 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 is essentially a cluster of suitably interconnected nonlinear elements of very simple form that possess the ability to learn and adapt. 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. These networks are characterized by their topology, the way in which they communicate with their environment, the manner in which they are trained, and their ability to process in formation. ANNs are being used to solve AI problems without necessarily creating a model of a real dynamic system.

For improving the performance of a UPQC, a multilayer feedforward- type ANN-based controller is designed. This network is designed with three layers, the input layer with 1, the hidden layer with 21, and the output layer with 1 neuron, respectively. The large data of the dc-link current for and intervals from the conventional method are collected and are stored in the Matlab workspace. These data are used for training the NN. The activation functions chosen are tan sigmoid 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

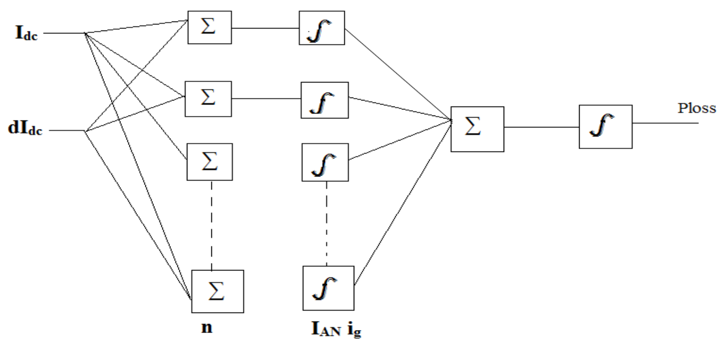


Fig.4 Exploded diagram of the artificial neural network.

The training algorithm used is Levenberg–Marquardt back propagation (LMBP). The MATLAB programming of ANN training is given as follows [1]:

```
net=newff(minmax(P),[1,21,1],{'tansig','tansig','purelin'},'trainlm');
```

```
net.trainParam.show=50;
net.trainParam.lr=0.05;
net.trainParam.mc=0.95;
net.trainParam.lr_inc=1.9;
net.trainParam.lr_dec=0.15;
net.trainParam.epochs=5000;
net.trainParam.goal=1e-6;
[net,tr]=train (net,P,T);
a=sim (net,P);
gensim (net,-1);
```

V. FUZZY LOGIC PI CONTROLLER

The PI like fuzzy logic controller consists of rules of the form If e(t) is (fuzzy set) and Δ e(t) is (fuzzy set), then Δ u(t) is (fuzzy set).

Where (fuzzy set) is the membership function of linguistic value the natural language equivalent of above symbolic description reads as follows:

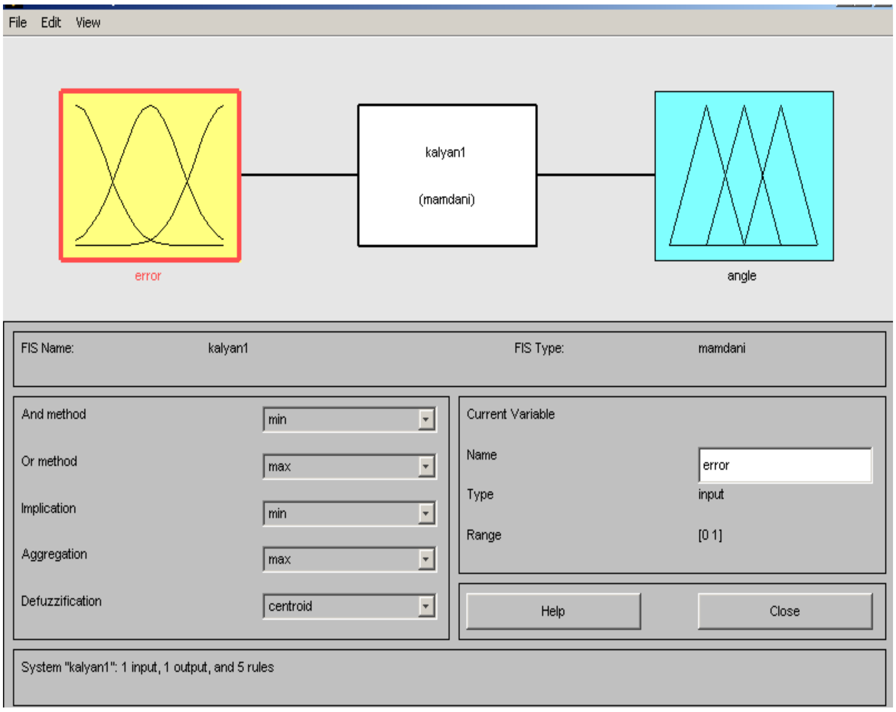
For each sampling time t, If the value of error has the property of being (linguistic value) and the value of change-off-error has the property of being (linguistic value), then change-of-control output has the property of being (linguistic value).

For the sake of simplicity, we will omit the explicit reference to sampling time K since such a rule expresses a caused relationship between process state and control output variables, which holds for any sampling time t. Thus the final symbolic representation of the above rule is

If e is (fuzzy set) and Δ e is (fuzzy set), Δu is (fuzzy set). In this case, to obtain the value of the control output variable r(t), the change-of-control output Δu(t) is added to u(t-1). It is to be stressed here that this takes place outside the PI-like fuzzy logic controller, and is not reflected in the rules themselves.

Editing of Fuzzy Interface System

In this we edit the rules, ranges of each membership functions for inputs and outputs. The step by step procedure



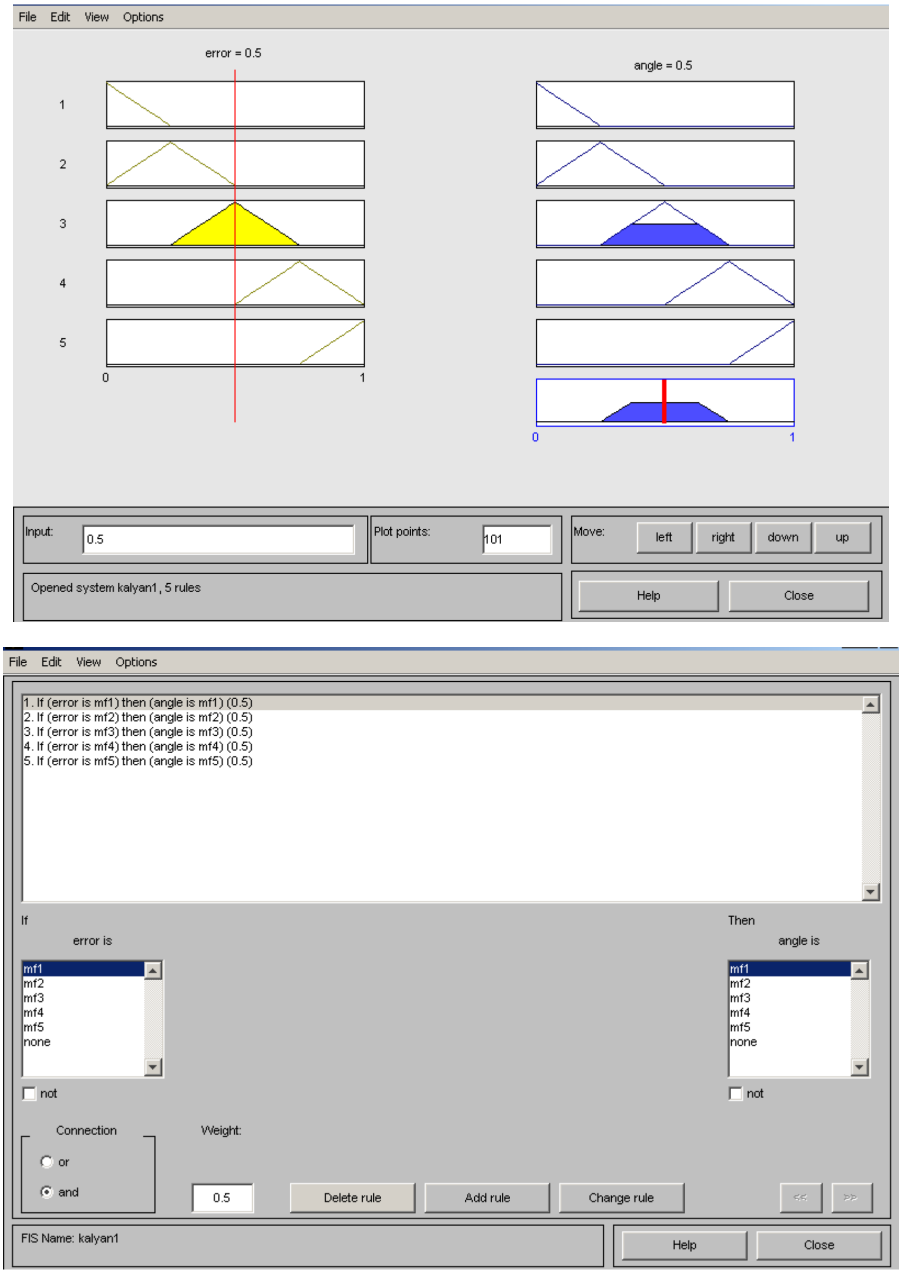


Fig.5 fuzzy interface system

Step 1:- Edit the membership functions.
Input 1:- trimf, number 3, range
OUTPUT:- trimf, number 4, range
Step 2:- Edit rules. Step (a): first take the relating rules.
Step (b): add the rules respectively by selecting each Variable.
Step 3:- Export the FIS editor to the workspace
Step 4:- Link this FIS editor to the FIS rule viewer.

VI. SIMULATION DIAGRAM

The block diagram of CSI based UPQC which is connected to the transmission lines with three phases connected between source and non linear load is shown below. In this simulation diagram a DC link (inductor) is connected between the two inverters.

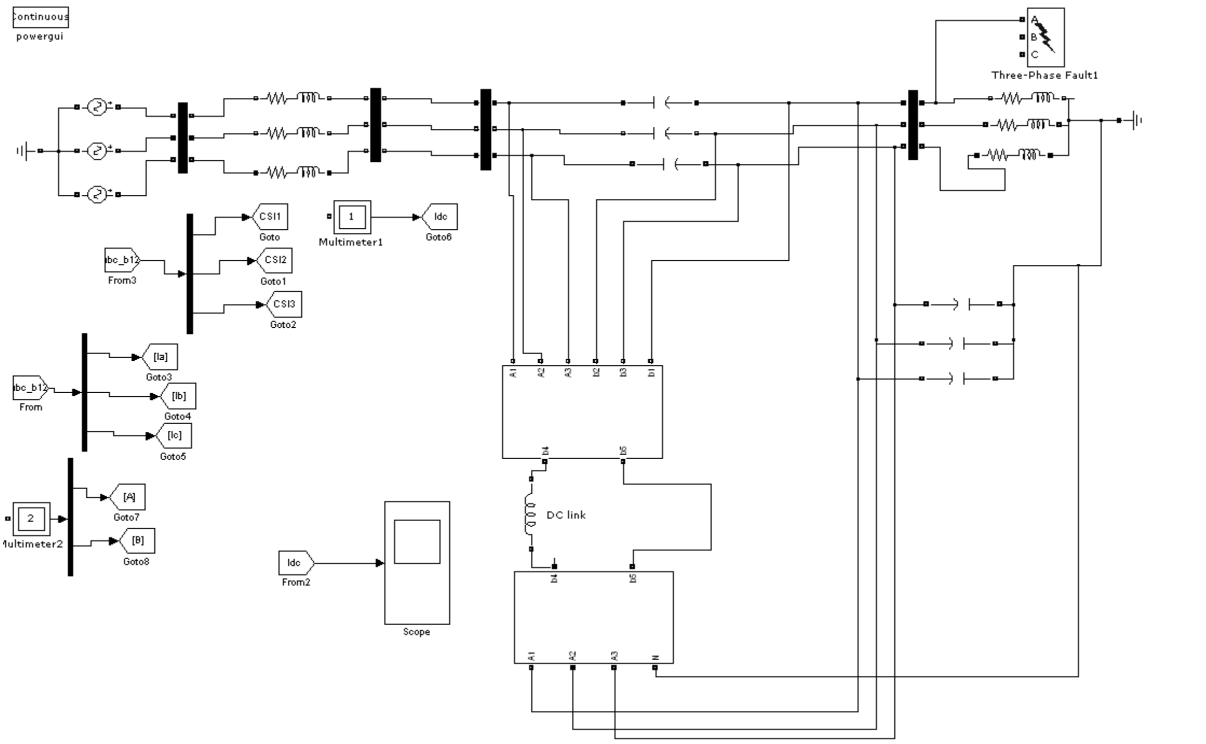


Fig.6 Simulation diagram of CSI based UPQC

In this section, the performance comparison of PI, ANN and FUZZY PI controllers in controlling the dc-link current of an UPQC is performed. Total simulation is performed for 0.3sec. The performance of the shunt active filter of the UPQC with the PI controller is given in Fig.7 while that with an ANN controller is given in Fig.8 and also with Fuzzy PI controller is given in Fig.9.

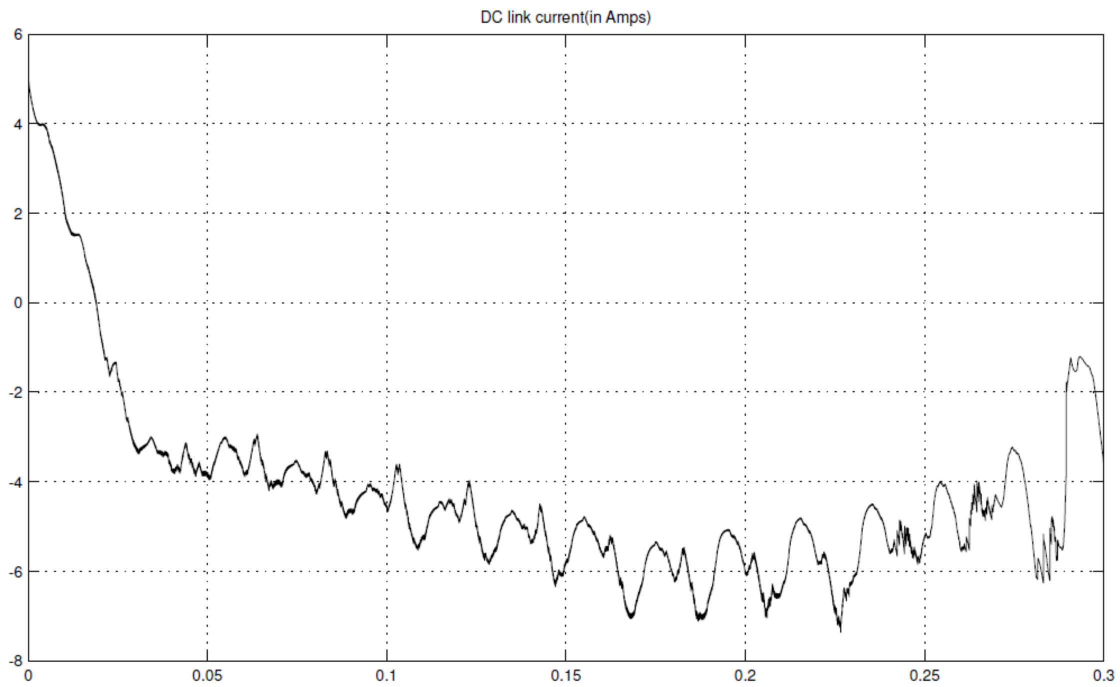


Fig.7 Performance of the shunt active filter of the UPQC with the PI controller for load perturbations

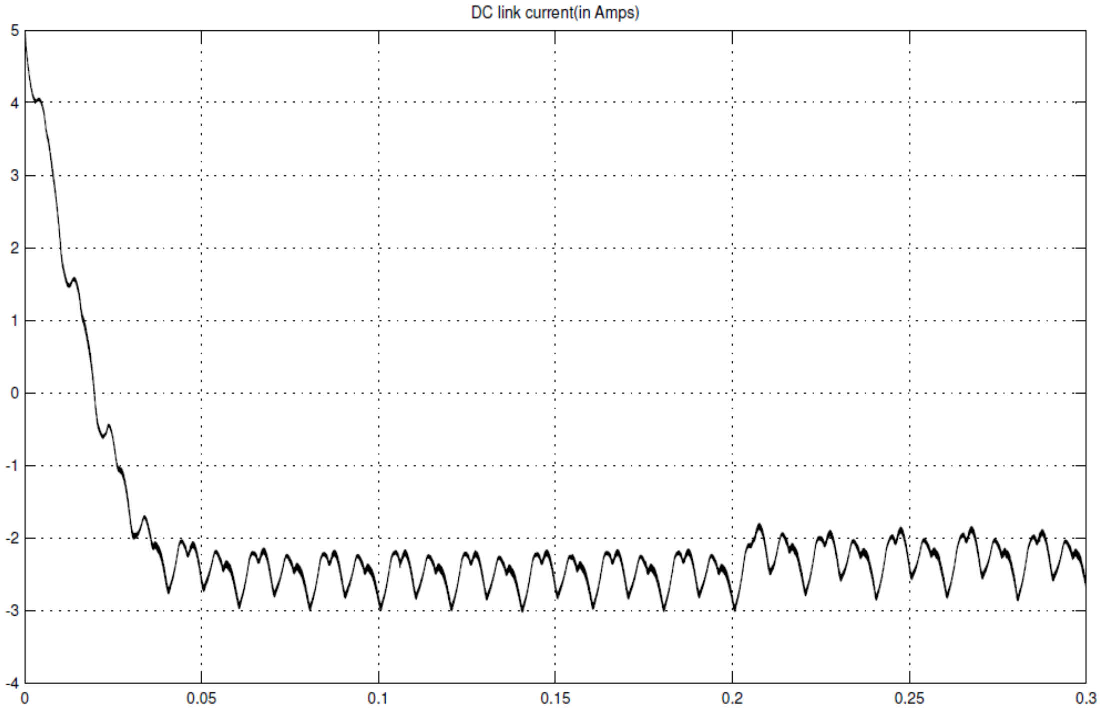


Fig.8 Performance of the shunt active filter of the UPQC with the ANN controller for load perturbations

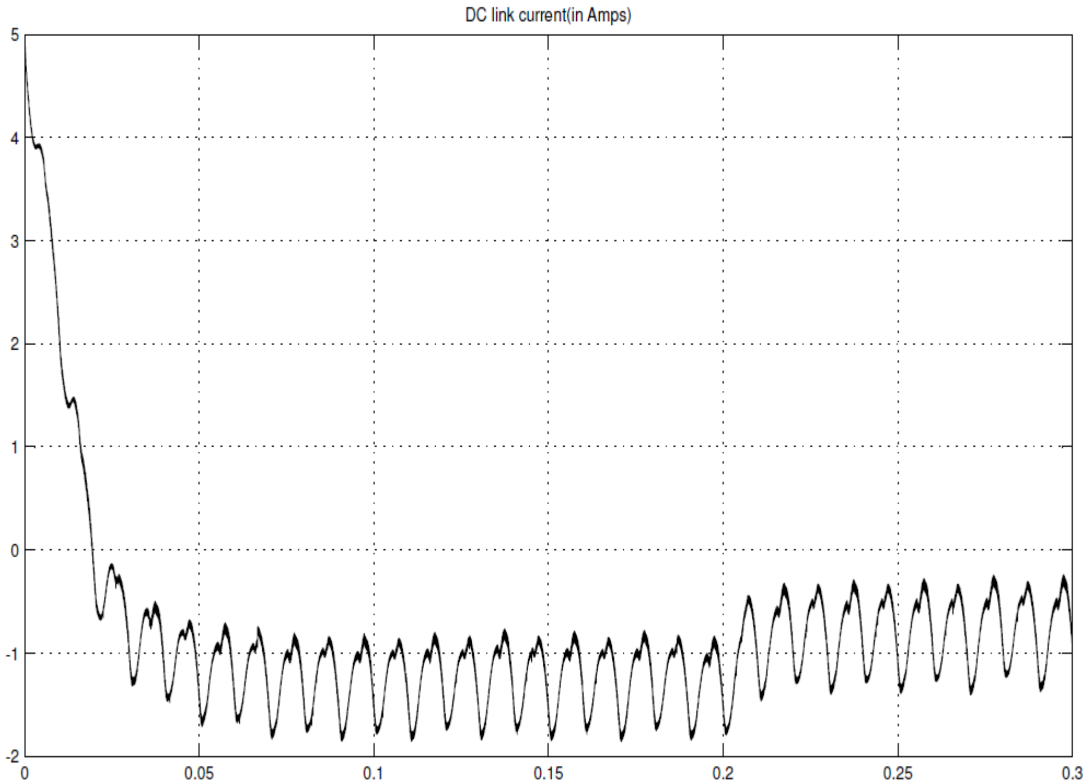


Fig.9 Performance of the shunt active filter of the UPQC with the FUZZY PI controller for load perturbations

In this comparison it is observed that PI controller is not effectively stabilizing the DC link current at initial conditions and also when there is disturbance in load. On the other hand ANN controller and Fuzzy PI controllers are taking less time to stabilize and when compared between the three controllers, Fuzzy PI controller is more effectively stabilizing the DC link than ANN controller. Also it is controlling the DC link with less distortion.

VII. CONCLUSION

The performance of the UPQC mainly depends upon how accurately and quickly reference signals are derived. It was observed that the power conditioner should have a stable DC link current for the better compensation of load harmonics and voltage sags. However, its performance using the conventional PI controller was not satisfactory especially with respect to transient conditions. In order to improve its response time, the artificial-intelligence-based ANN controller and Fuzzy Logic controller are proposed, and their performances are analyzed by using MATLAB simulation. PI, ANN and Fuzzy PI (simply fuzzy controller) controllers are proved to be better for stabilizing the Dc link current compared to PI controller. Fuzzy PI controller is more effectively stabilizing the DC link than ANN controller and PI controller. Also it is controlling the DC link with less distortion than both ANN and PI controllers.

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