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COMPARISION OF PI CONTROLLER & FUZZY LOGIC CONTROLLER USING UNIFIED POWER QUALITY CONDITIONER

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ABSTRACT*:Application of power electronic based loads in industry has increased the importance and application of power quality studies. Power electronic equipment's with nonlinear loads are broadly used in domestic, commercial and industrial applications causing for distortion in current and voltage waveforms. The electronic devices are very sensitive to disturbances and thus the industrial loads become less tolerant to power quality problems like voltage dips, voltage sags, voltage flickers, harmonics and load unbalance, real and reactive power problems etc. In addition to these, the other power quality problems have appeared in the system that reduces the overall efficiency of the system. In this paper, Unified Power Quality Conditioner (UPQC) has been modeled for both active and reactive power compensation using PI and fuzzy control strategy. The behavior of UPQC has been analyzed and the system has been modeled using MATLAB and the results have been compared.*

KEYWORDS: UPQC, PI Controller, Fuzzy controller,Active power filter, Power Quality.

1.INTRODUCTION

Power Quality is an important issue that is increasingly to electricity consumers because of sensitive equipment and non-linear loads are now more commonplace in both domestic environment and power sectors. We should have awareness of power quality is developing amongst electricity users. The electricity supplies that were once considered acceptable by electricity companies and users are now often considered a problem to the users of everyday equipment. The solution to power quality problems is available to the both the distribution network operator and the end users. Active Power Filters (APFs) are shunt, series and vice versa to compensate for current and voltage based distortions for better quality solutions. A Unified Power Quality Conditioners (UPQCs) have been introduced as a powerful and advanced compensating device to simultaneously deal with current and voltage related problems. [1-3].

An UPQC, composed of shunt and series APFs, is capable of compensating voltage distortions at the supply side as well as current harmonics at the load side to make the load voltage and the supply current become pure sinusoidal. However, despite its effectiveness in power quality improvement, the application of the UPQC in practice is quite limited. Design of passive components for the proposed system is to achieve good performance. In this paper unified power quality conditioner (UPQC) is being used as a universal active power conditioning device to mitigate both current as well as voltage harmonics at a distribution end of power system network[4-7]

The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. The unified power quality conditioner (UPQC) has been modeled for both active and reactive power compensation using fuzzy control strategy. The Fuzzy Logic controller is used to solve the non-linear problems efficiently. A block diagram of the proposed system is shown in figure 1

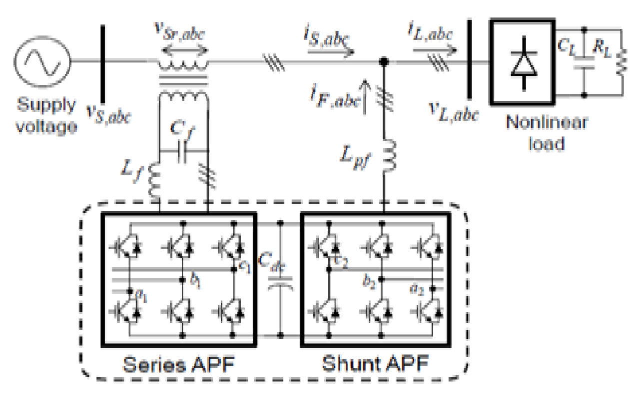

Fig-1 Block Diagram of proposed system

The series active filter connected in series through an injection transformer is commonly termed as series filters (SAF). It acts as a controlled voltage generator. It has capability of voltage imbalance compensation, voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). In addition to this, it provides harmonic isolation between a sub-transmission system and a distribution system. The second unit connected in parallel with load, is termed as Shunt Active Filter. It acts as a controlled current generator. The shunt active filter absorbs current harmonics, compensate for reactive power and negative sequence current injected by the load. In addition, it controls dc link current to a desired value. In power line conditioner one more element is a dc link inductor, which acts as energy storage device. A small amount ofdc power supply is required to operate active power filter for harmonic compensation. The dc link inductor functions as dc power supply sources and hence does not demand any external power source. However, in order to maintain constant dc current in the energy storage element, a small fundamental current is drawn to compensate active filter losses [8-11].

2. PI CONTROLLER

The PI controller is a generic control loop feedback mechanism widely used in industrial control systems and other applications. PI controller algorithm involves two separate parameters, the Proportional (P) and the Integral (I). The proportional value determines the reaction to current error wherethe integral value determines the reaction based on the sum of recent errors. The equation form of PI controller is given by

$$Y(t) = K_p e(t) + K_t \int_0^t e(t)dt \quad (1)$$

K_P and K_t represent the proportional gain and integral gain respectively; y(t) represents the output of the controller. The voltage error value e is fed to the PI controller. The transfer function model of PI controller is shown in Figure 2

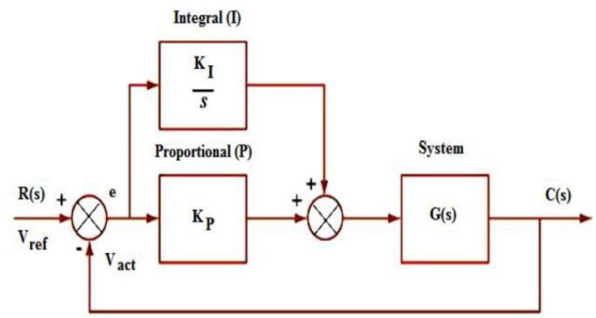

Fig-2 Transfer function model of PI controller

To maintain the DC-link voltage at the reference value, the DC-link capacitor needs a certain amount of real power, which is proportional to the difference between the actual and reference voltages.

The power required by the dc-link capacitor can be expressed as,

$$P_{dc} - K_p(V_{ref} - V_{act}) + K_I \int_0^t (V_{ref} - V_{act})dt \quad (2)$$

If the values of K_P and K_I are large, DC-bus voltage regulation is dominant and steady state dc-bus voltage error is low. On the other hand, if K_P and K_I are small, the real power unbalance gives little effect to the transient performance. Therefore, proper selection of K_P and K_I are essentially important to satisfy the control performance and maintain power required by capacitor. In the first approach, K_P and K_I values are chosen based on trial and error method.

3. MODELING OF PI CONTROLLER

Conventionally, PI controller has been used for regulating the voltage of DC link capacitor. The output of PI controller is applied to current control system of shunt inverter, to maintain the DC capacitor voltage by drawing the required amount of active power from the grid. DC link voltage control using a PI controller is shown in Figure 3.

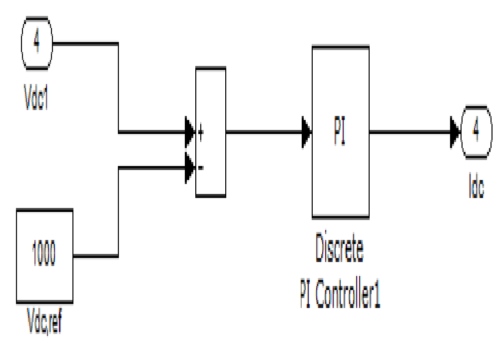

Fig-3 DC link voltage control using PI controller

In case of PI controller, proportional gain (K_p) and integral gain (K_I) values plays an important role in voltage regulation. Values of K_P and K_I are chosen by repeated simulation by keeping in mind the following points: Too much increase in proportional gain leads to instability in control system and too much reduction decreases the responding speed of control system. Integral gain of controller corrects the steady state error of the voltage control system.

Also, too much increase in its value may also leads to instability. Thus, values of K_P and K_I used in simulation are 0.8 and 25 respectively. In order to achieve the desired performance of UPQC in dynamic conditions of power system such as voltage sags/swells, load change, unbalance etc., response of DC link voltage control should be as fast as possible while retaining capacitor voltage with a minimum delay time and lower overshoot. Conventionally PI controller is used for regulation of DC link voltage constant whose response is system parameters dependent.

4. FUZZY LOGIC CONTROLLER

In this figure 4, explain the proposed system of UPQC based Fuzzy Logic controller. UPQC is the integration of series (APFse) and shunt (APFsh) active power filters, connected back-to-back on the dc side, sharing a common DC capacitor. The series active filter connected in series through an injection transformer is commonly termed as series filters (SAF). It acts as a controlled voltage generator.It has capability of voltage imbalance compensation, voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC).

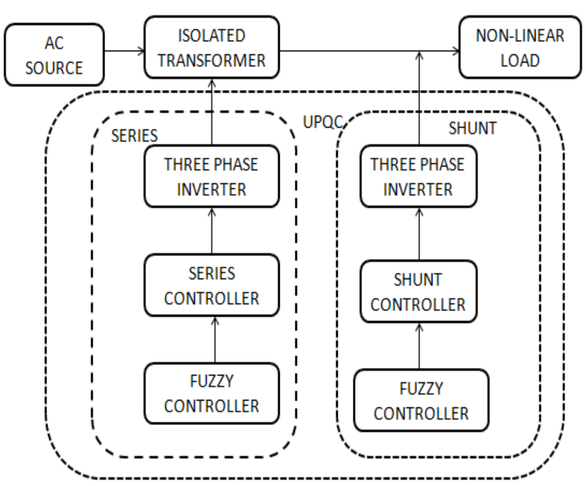

Fig-4 Block Diagram of Fuzzy Logic Controller

In addition to this, it provides harmonic isolation between a sub-transmission system and a distribution system. The shunt active power filter connected in parallel with load. It acts as a controlled current generator. The shunt active filter absorbs current harmonics, compensate for reactive power and negative sequence current injected by the load.In addition, it controls dc link current to a desired value. In power line conditioner one more element is a dc link inductor, which acts as energy storage device. A small amount of dc power supply is required to operate active power filter for harmonic compensation. The dc link inductor functions as dc power supply sources and hence does not demand any external power source. However, in order to maintain constant dc current in the energy storage element, a smallfundamental current is drawn to compensate active filter losses.

Fuzzy Logic controller is the systematic approach to control a nonlinear based procedure depending on the knowledge and experience based of human being. A fuzzy controller can use multiple inputs and multiple output variables.Inverter operates from a dc voltage source or a dc current source and converts it into ac voltage or current. Pulse generator is used to generate PWM pulses to make a switching signal for operating the inverter. RL or RC Load are connected. The overall function of UPQC mainly depends on the series and shunt APF controller.

5. THE OPERATION OF FUZZY CONTROLLER

In a fuzzy logic controller, the control action is determined from the evaluation of a set of simple linguistic rules. The development of the rules requires a thorough understanding of the process to be controlled, but it does not require a mathematical model of the system. The design of a fuzzy logic controller requires the choice of membership functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs.

To achieve finer control, the membership functions near the zero regions should be made narrow. Wider membership functions are away from the zero regions provides faster response to the system. Hence, the membership functions should be adjusted accordingly. After the appropriate membership functions are chosen, a rule base should be created. It consists of a number of Fuzzy If-Then rules that completely define the behavior of the system. These rules very much resemble the human thought process, thereby providing artificial intelligence to the system.

The error and change of error are used numerical variables from the real system. To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as

NB (negative big)

NM (negative medium)

NS (negative small)

ZE (zero)

PS (positive small)

PM (positive medium)

PB (positive big) and presented in input and output normalized membership functions.

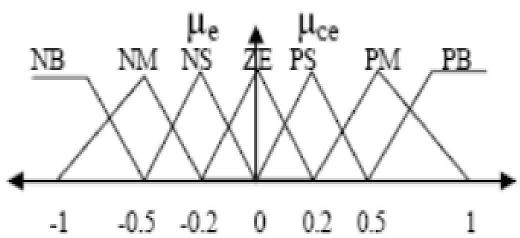

Fig-5 Input Normalized Membership Function

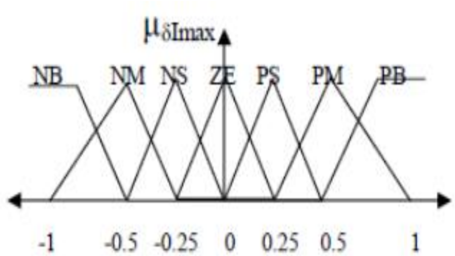

Fig-6 Output normalized membership function

The fuzzy controller is characterized as follows

(i) Seven fizzy sets for each input and output

(ii) Triangular membership functions for simplicity

(iii) Fuzzification using continuous universe of discourse

(iv) Implication using Mamdani‟s 'min' operator

(v) Defuzzification using the 'centroid' method.

A. Fuzzification

The term fuzzification means to fuzzify the data. This is done by converting the classical set to fuzzy set. For this process we need different fuzzifiers such as Triangular, Trapezoidal, Singleton and Gaussian. With the help of these fuzzifiers we assign some membership function to each and every input and convert it into fuzzy set.

B. Membership Function

It is a graph between input and the membership value, which varies from 0 to 1. The membership function provides impreciseness to the fuzzy logic.

There are various types of membership functions,

i. Trapezoidal

ii. Triangular

iii. Gaussian

iv. Sigmoid

v. Piecewise linear

C. Fuzzy Inference Engine

It consists of knowledge base, in which the rules are framed. Fuzzy inference engine can be broadly categorized into two types of methods:

i. Mamdani method

ii. Sugeno method

Mamdani method is a fuzzy inferencing method in which the linguistic logic is used to make the rules. Mamdani method is easy to implement, user friendly and widely accepted method of fuzzy inferencing. The reason being is its wide area of application to most of the problems. On the other hand sugeno method is based on mathematical analysis and calculations. It is more complex compared to the Mamdani method. Sugeno method works well with the linear systems. One major advantage is that it is computationally efficient.

D. Deffuzification

It is a process of converting a fuzzy set into classical set. It is the inverse process of fuzzification. It is of much importance as by deffuzification process we convert the fuzzy values back into the classical or crisp values. There are different methods for deffuzification such as the centroid method, bisector method, largest of maximum, middle of maximum and finally the smallest of maximum. Among all of this the most efficiently used defuzzification method is the centroid method.

A fuzzy controller can operate in a broad range of operations along with the variation of the parameters and load existence as compared to PI controllers. Depending on the control requirements and operational conditions of the DFIG, a fuzzy PI control strategy is designed. Input to the fuzzy PI controller is the error, which is continuously tracked and automatically corrected by the K_c and K_t controllers so as to achieve a dynamic performance.

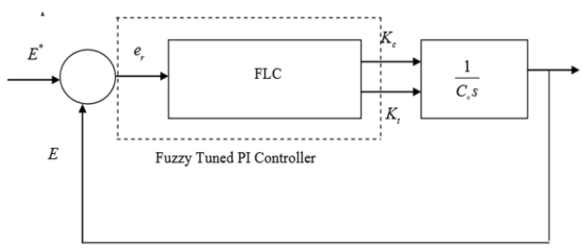

Fig-7 Block Diagram of Fuzzy Tuned PI Controller

K_c = Proportional Gain, K_t = Integral Gain

The input signal consists of nine membership functions and the two outputs each consisting of five membership functions.

6.THE RULE BASE OF FUZZY CONTROLLERS

The elements of this rule base table are determined based on the theory that in the transient state, large errors need coarse control, which requires coarse input/output variables; in the steady state, small errors need fine control, which requires fine input/output variables. Based on this the elements of the rule table are obtained as shown in below Tables.

Table-1 Rules Table of Fuzzy Controller

e	K_c	K_t
NVH (Negative Very High)	VH (Very High)	VL (Very Low)
NH (Negative High)	H (High)	L (Low)
NL (Negative Low)	N (Normal)	N (Normal)
NVL (Negative Very Low)	L (Low)	H (High)
N (Normal)	VL (Very Low)	VH (Very High)
PVL (Positive Very Low)	L (Low)	H (High)
PL (Positive Low)	N (Normal)	N (Normal)
PH (Positive High)	H (High)	L (Low)
PVH (Positive Very High)	VH (Very High)	VL (Very Low)

Table-2 Input Parameters for DC Link Voltage Control

Name	Type	Range
Negative Very High	Trapezoidal	[-5 -3 -1 -0.8]
Negative High	Triangular	[-1 -0.75 -0.5]
Negative Low	Triangular	[-0.8 -0.5 -0.2]
Negative Very Low	Triangular	[-0.5 -0.15 0.2]
Normal	Triangular	[-0.5 0 0.5]
Positive Very Low	Triangular	[-0.2 0.15 0.5]
Positive Low	Triangular	[0.2 0.5 0.8]
Positive High	Triangular	[0.5 0.75 1]
Positive Very High	Trapezoidal	[0.8 1 3 5]

7. SIMULATION & RESULTS

The PI and Fuzzy controller simulations are developed in MATLAB and the corresponding outputs are obtained. It can be noted that the input and output voltage, the input and output current, real and reactive power of the system shown in below figures.

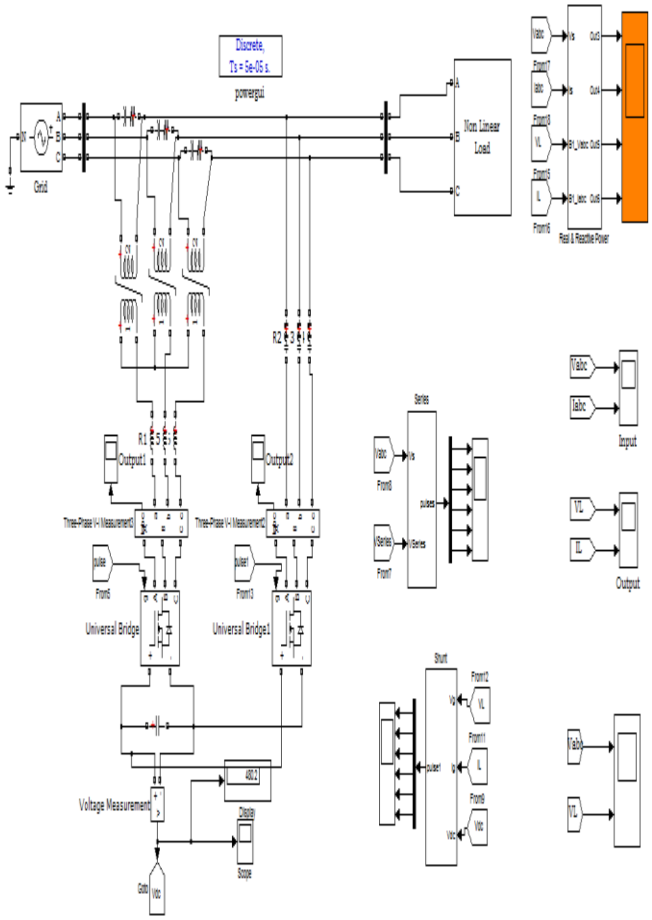

Fig-8 MATLAB simulation for PI controller

SIMULATION RESULTS FOR PI CONTROLLER

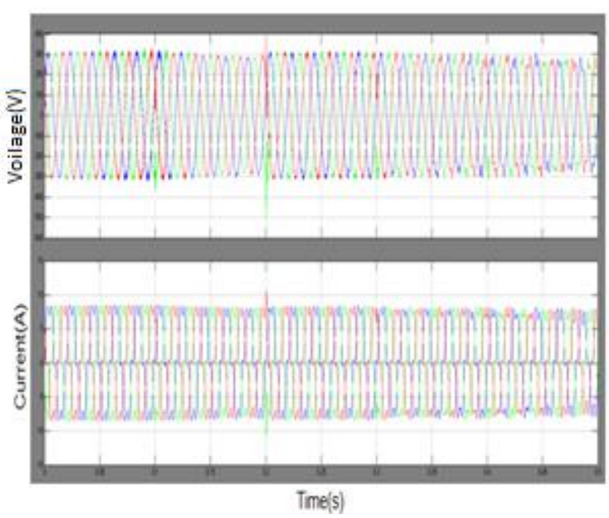

Fig-9 Input voltage and current

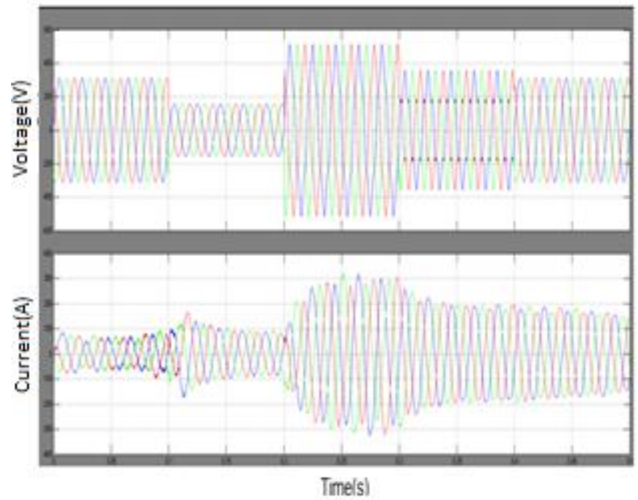

Fig-10 Output voltage and current

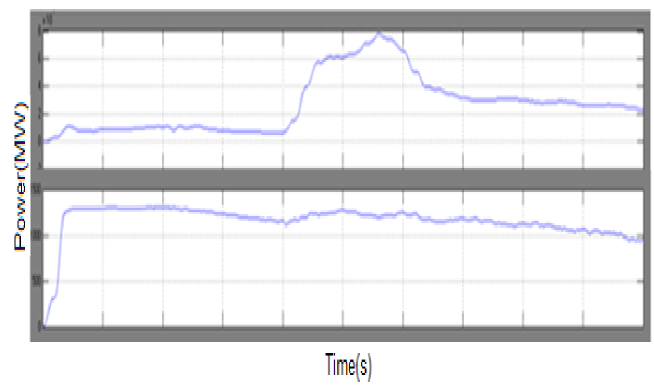

Fig-11 Real Power Input and output

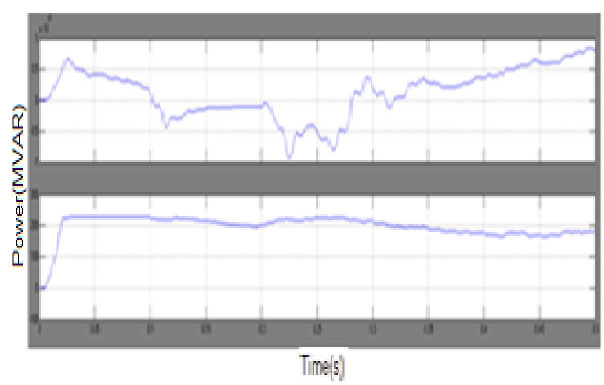

Fig-12 Reactive power Input and output for PI controller

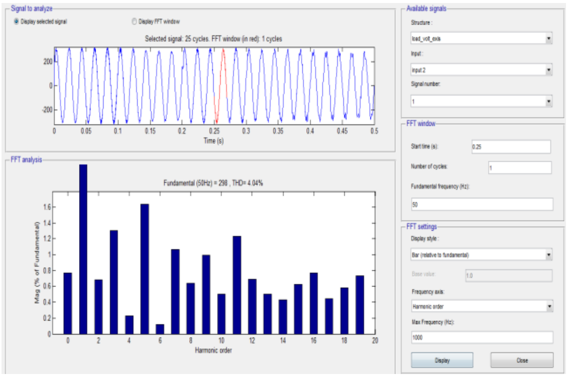

Fig-13 THD for PI Controller

The SIMULINK model is developed with PI and fuzzy controller and the results have been determined for non-linear load. Figure 9 shows the input voltage and input current of PI Controller. Figure 10 shows the output voltage and current of PI Controller. Figure11&12 shows the input and output of real & reactive power respectively. As shown in Fig. 13, the THD of PI Controller is 4.04%.

SIMULATION RESULTS FOR FUZZY CONTROLLER

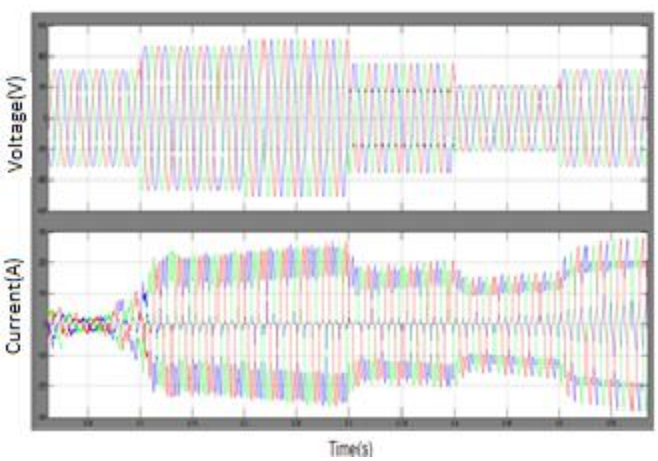

Fig-15 Input voltage and current

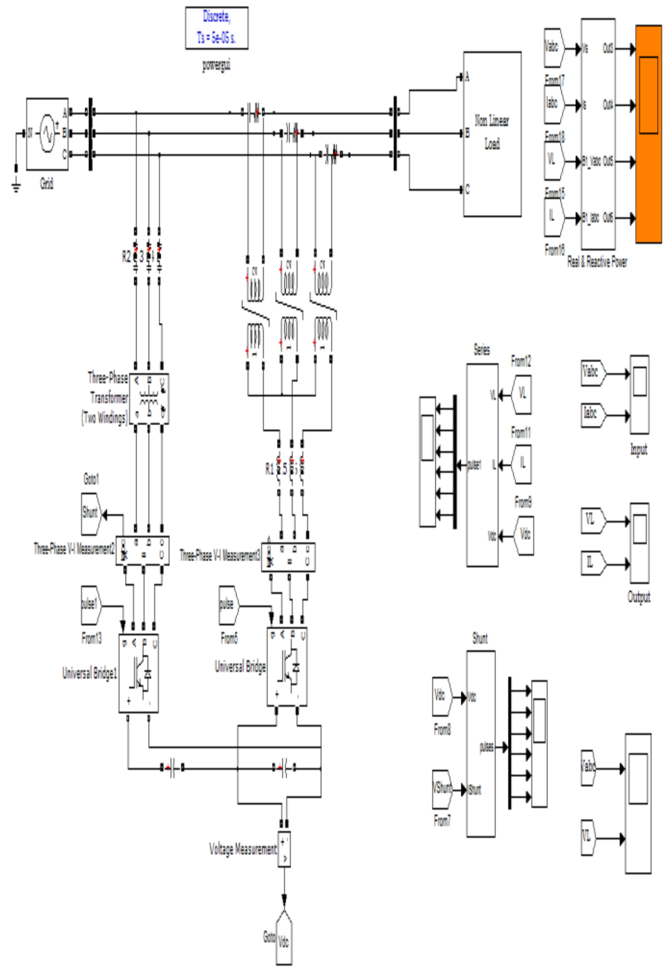

Fig-14 MATLAB simulation for fuzzy controller

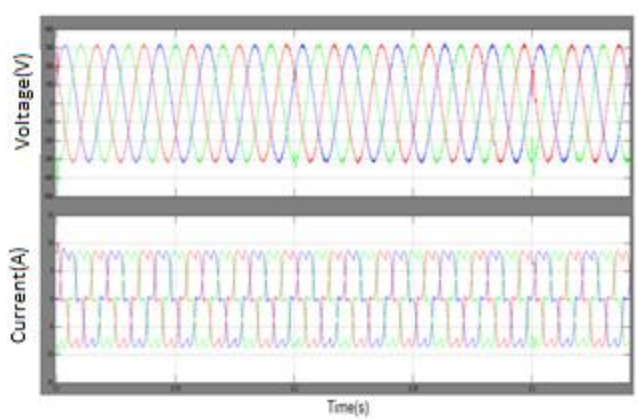

Fig-16 Output voltage and current

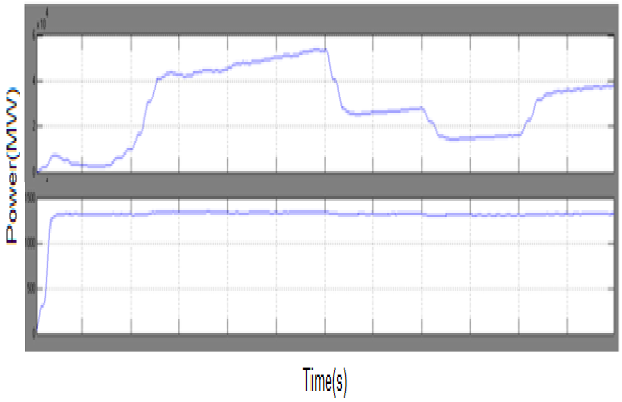

Fig-17 Real Power Input and output

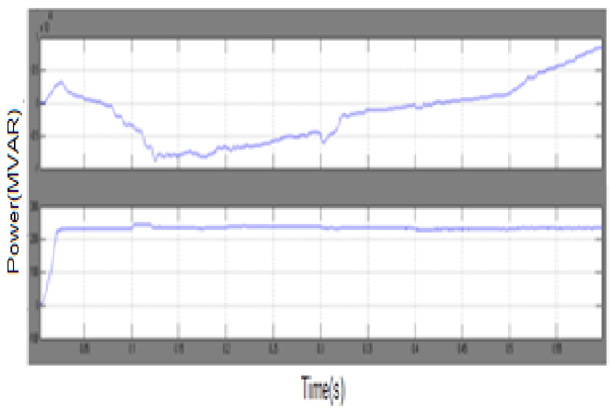

Fig-18 Reactive Power Input and output

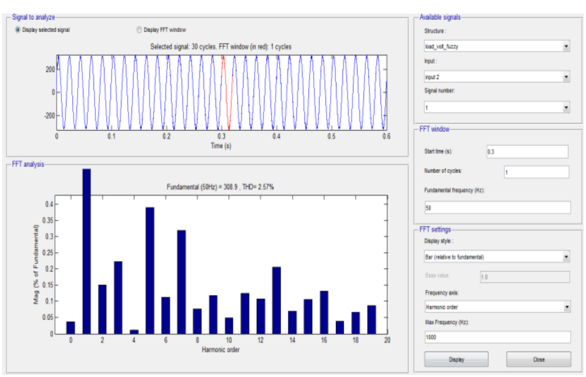

Fig-19 THD for Fuzzy Controller

Figure 15 shows the input voltage and current of Fuzzy Controller. Figure 16 shows the output voltage and current of Fuzzy Controller. Figure17&18 shows the input and output of real & reactive power respectively. As shown in Fig. 19, the THD of Fuzzy Controller is 2.57%.

Table 3. Comparison of the results

S.NO	FACTOR	PI CONTROLLER	FUZZY CONTROLLER
1.	Total Harmonic Distortion	4.04%	2.57%
2.	Dynamic Response	Slow	Fast
3.	Capacitor Charging	Slower	Faster
4.	Capacitor voltage balance under unbalanced load condition	stable	stable
5.	Source current THD with switching RL load	3.52%	3.26%
6.	Source Voltage THD with switching RL load	1.89%.	1.27%.

From the above table 3 observed that UPQC is able to maintain sinusoidal voltage and current waveforms at source and load end side. The Dynamic Response of PI controller is 0.20sec and Dynamic Response of Fuzzy controller is 0.10sec. the sag gets cleared is of duration 0.16sec with PI controller, while of 0.03sec with fuzzy controller. Hence from above analysis, though fuzzy controller shows faster response, the performance of fuzzy controller is much better than PI controller as it has steady state accuracy and better THD values.

8. CONCLUSION

Unified PowerQuality Conditioner is made to mitigate all types of power quality disturbances like voltage sag and swells, voltage harmonics, voltage unbalance, current harmonics, reactive power problem and poor power factor. This paper has been mainly concentrated on system configuration and the control topology required for it.The proposed system we designed the Unified Power Quality Conditioner with the control technique by PI and Fuzzy controller. This paper concludes that fuzzy logic controller based UPQC has the better dynamic response and total harmonic distortion is 57% less whencompared to PI controller.

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