Enhancement of Power Quality by using Unified Power Quality Conditioner with PID and Fuzzy Logic Controller

R V D Rama Rao
Assoc. Professor
Narasaraopeta Engineering College,
Narasaraopet – 522 601, India

Dr.Subhransu Sekhar Dash
Professor
SRM University,
Chennai,India

ABSTRACT

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. The performance of UPQC mainly depends upon how quickly and accurately compensation signals are derived. The steady state and dynamic operation of control circuit in different load current and/or utility voltages conditions is studied through simulation results. The presented method has acceptable dynamic response with a very simple configuration of control circuit. This paper presents performance validation of Current Source Inverter (CSI)-based UPQC using Fuzzy Logic Controller (FLC) and Results are compared with conventional PID Controller and improvements are observed by FLC. The FLC-based compensation scheme eliminates voltage and current magnitude of harmonics with good dynamic response. Extensive simulation results using Matlab/Simulink for RL load connected through an uncontrolled bridge rectifier validates the performance of FLC compensator.

Keywords

active power filter; Fuzzy Logic Controller, FLC; current source inverter, CSI; harmonics; power quality; unified power quality conditioner.

1. INTRODUCTION

Improvement of Power Semiconductor Technology since 1970, made it possible using these devices in electric utility applications. One of the recent developed of these applications is unified power quality conditioner (UPQC). According to the basic idea of UPQC, it consists of back-to-back connection of two three-phase active filters (AFs) with a common dc link. The point of common coupling (PCC) could be highly distorted, also the switching ON/OFF of high rated load connected to PCC may result into voltage sags or swells on the PCC has been discussed [2]-[3]. There are several sensitive loads, such as computer or microprocessor based AC/DC drive controller, with good voltage profile requirement; can function improperly or sometime can lose valuable data or in certain cases get damaged due to these voltage sag and swell conditions. One of the effective approaches is to use a unified power quality conditioner (UPQC) at PCC to protect the sensitive loads. A UPQC is a combination of shunt and series APFs, sharing a common dc link has been well presented in [4]. It is a versatile device that can compensate almost all power quality problems such as voltage harmonics, voltage unbalance, voltage flickers, voltage sags & swells, current harmonics, current unbalance, reactive current, etc. Recently more attention is being paid on mitigation of voltage sags and swells using UPQC. The swells are not as common as sags, but the effects of a swell can be more destructive than sag. For example, the excessive over voltage during swell condition may cause breakdown of components or equipments. The common cause of voltage sag and swell is sudden change of line current flowing through the source impedance. The steady state analysis of UPQC during voltage sag and swells on the system well presented in [5]- [6]. The main objective is to maintain the load bus voltage to be sinusoidal and the major concern is the flow of active and reactive power during these conditions. It plays animportant role to select the KVA ratings of both shunt and series APFs. Among different new technical options available to improve power quality, unified power quality conditioner has found to be more promising for compensation of current as well as voltage harmonics simultaneously. As per available literature, use of UPQC for mitigation of voltage and current harmonics has been presented in [1]. It is commonly configured with two voltage source converters connected back to back through a DC link capacitor. However, voltage source topology of UPQC has a drawback of slow control of onverter output voltage and no short circuit protection [7]-[8]. In addition, when the active rectifier inside UPQC is used as a power factor corrector, DC bus voltage oscillations appears which makes the control of the series filter output voltage more difficult. Before mentioned problems are overcome by using current source inverter (CSI). CSI-based UPQC has a faster phase voltage control loop and inherent short circuit protection capability. It also minimizes the cost as in this case passive filter connection between UPQC and the load is not necessary. The only disadvantage of CSI-based UPQC is that its dc link inductor is bulky and heavy which leads to high dc link losses. It uses synchronously rotating frame to derive reference signals, which has increased time delay in filtering dc quantities. The concept of FLC is to utilize the qualitative knowledge of a system to design a practical controller [9]. For a process control system, a fuzzy control algorithm embeds the intuition and experience of an operator, designer and researcher. The control doesn't need accurate mathematical model of a plant, and therefore, it suits well to a process where the model is unknown or ill-defined and particularly to systems with uncertain or complex dynamics [10]. In this paper the application of fuzzy logic in control of shunt and series active power filters used a hystersis band comparator for control of three-phase active power filter. This paper presents a novel method for derivation of compensation signals in CSI-based UPQC using Fuzzy logic Controller.The performance of the system is verified by extensive simulation on Matlab/Simulink

2. BASIC CIRCUIT CONFIGURATION

Fig.1 shows the general power circuit configuration of UPQC. This system consists of a PAF and a SAF. The control circuit of UPQC, generates the reference compensating currents and voltages of PAF and SAF in instantaneous and simultaneous manner,respectively.

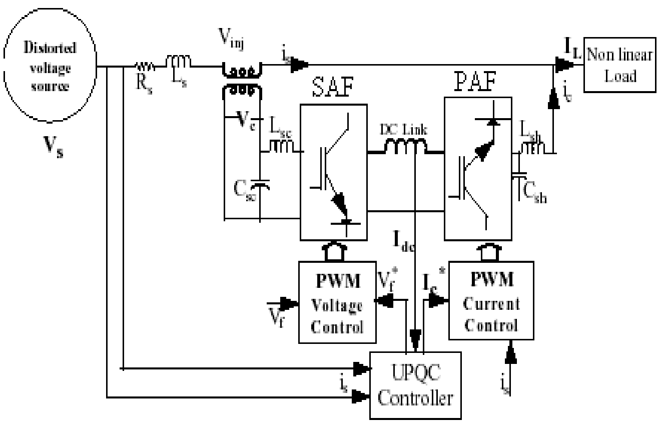

Fig.1 Power circuit configuration of UPQC

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 (PAF). 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 [11]. 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 small fundamental current is drawn to compensate active filter losses [12].The text should be in two 8.45 cm (3.33") columns with a .83 cm (.33") gutter.

3. STEADY STATE POWER ANALYSIS

Equivalent circuit diagram of a Unified Power Quality Conditioner is as shown in fig.2 *Vs* is the supply voltage,V_{ac},I_{ac} are the series compensation voltage, shunt compensation current and V_{load} , I_{load} are the load voltage and current respectively. The source voltage may contain negative, zero as well as harmonic components. The per phase voltage of the system can be expressed as

$$V_a = V_{1pa} + V_{1na} + V_{10a} + \sum_{K=2}^{\infty} V_{Ka} \sin(k\omega t + \theta_{Ka}) \quad (1)$$

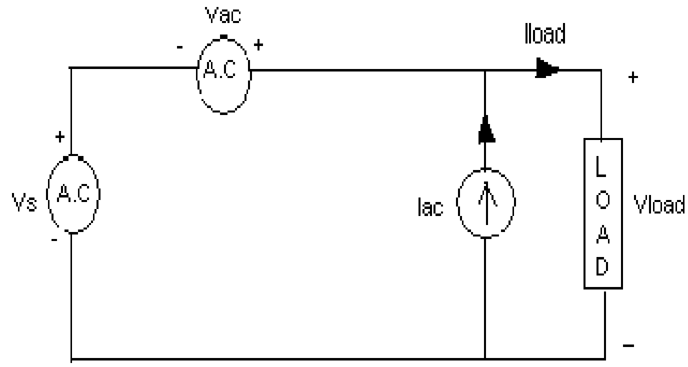

Fig.2 Equivalent circuit diagram of an UPQC

where is V_{1pa} the fundamental frequency positive sequence components, and V_{1na} and V_{10a} are negative and zero sequence components respectively. The last term of equation represents the harmonic content in the voltage. In order for the load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage of

$$V_{ah} = V_{1na} + V_{10a} + \sum_{k=2}^{\infty} V_{ka} \sin(k\omega t + \theta_{ka} \quad (2)$$

The functions of the shunt active filter is to provide compensation of the load harmonic current, load reactive power demand and also to maintain DC link current constant[14]- 15]. The per phase load current of shunt active filter is expressed as

$$i_{al} = I_{1pm} \cos(\omega t - \theta_1) + I_{a\ln} + \sum_{K=2}^{\infty} i_{alk} \quad (3)$$

$$= I_{ipm} \cos\omega t \cos\theta_1 + I_{1pm} \sin\omega t \sin\theta_1 + I_{a\ln} + \sum_{K=2}^{\infty} i_{alk} \quad (4)$$

In order to compensate harmonic current and reactive power demand the shunt active filter should produce a current of

$$I_{ah} = I_{1pm} \sin\omega t \sin\theta_1 + I_{a\ln} + \sum_{K=2}^{\infty} i_{alk} \quad (5)$$

So that the source current will be

$$i_{as} = i_{al} - i_{ah} = I_{1pm} \cos\omega t \cos\theta_1 \quad (6)$$

This is a perfect harmonic free sinusoidal current in phase with voltage.

4. CONTROL PHENOMENA

It is evident from above discussion that UPQC should separate out the fundamental frequency positive sequence components first from the other components. Then it is required to control both series and shunt active filter to give output as shown in equations (2) and (5) respectively. The control strategy uses a PLL based unit vector template for extraction of reference signal from the distorted input supply. In order for the load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage equal to equation (2). The reference load voltages are obtained by multiplying the unit vector templates with a constant equal to peak amplitude of fundamental input voltage [16]. The compensation signals for series filter are thus obtained by comparing these reference load voltages with actual source voltage, compensation signals are compared with actual signals at the terminals of series filter and the error is taken to hysteresis controller to generate the required gating signal for series filter. The shunt APF compensates current harmonics in addition to maintaining the dc link current at a constant level [17].

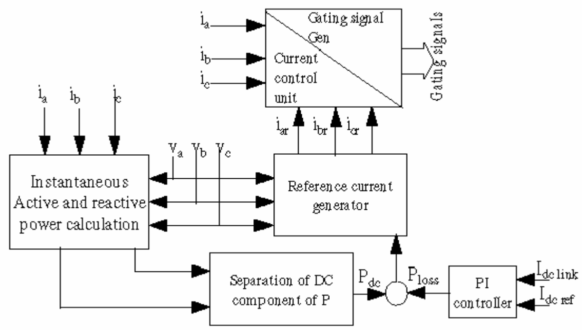

Fig.3 Control diagram of shunt active filter

To achieve this, dc link current of the UPQC is compared with a constant reference current of magnitude equal to peak of harmonic current. The error between measured dc link current and reference current is processed ina PI controller. The output of PI controller is added to real power loss component to derive reference source current Instantaneous active and reactive power in orthogonal coordinates are can be calculated from the relevant formulae[18]-[20]. The reference currents are then; compared with actual source current in a hystersis controller band to derive the switching signals to shunt inverter. Series active filter and shunt active filter control circuits are given below Fig.3 and Fig.4 respectively.

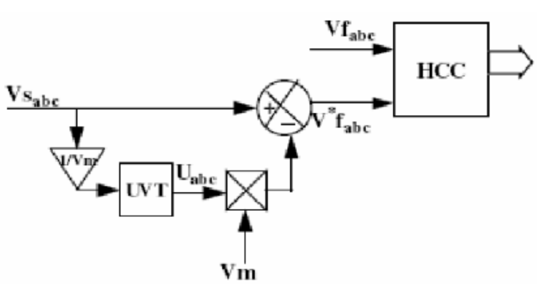

Fig.4 Control diagram of Series active Filter

5. DESIGNING OF UPQC AND TUNING OF FUZZY LOGIC CONTROLLER

The structure of a complete fuzzy control system is composed from the following blocs: Fuzzification, Knowledge base, Inference engine, Defuzzification. The fuzzification module converts the crisp values of the control inputs into fuzzy values. A fuzzy variable has which are defined by linguistic variables (fuzzy sets or subsets) such as low, Medium, high, big, slow where each is defined by a gradually varying membership function. In fuzzy set terminology, all the possible values that a variable can assume are named universe of discourse, and the fuzzy sets (characterized by membership function) cover whole universe of discourse. The shape fuzzy sets can be triangular, trapezoidale, etc To verify the performance of UPQC the system was simulated using Simulink Power System Blockset in Matlab. The aforementioned analysis and design was done in continuous domain. However, to investigate the behaviour of the system with digital based controller in future experimental work, the UPQC system was simulated in discrete domain. All the compensators are implemented using equivalent discrete blocks.

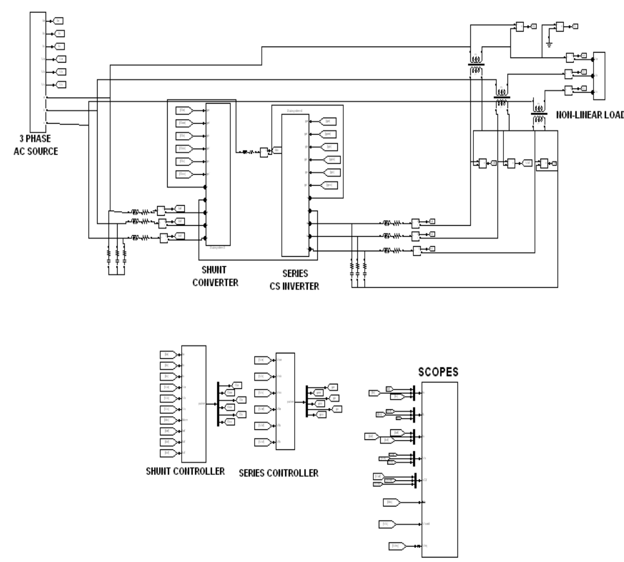

Fig.5 Simulink Model of UPQC with Fuzzy Controller

The compensator output depends on input and its evolution. The chosen configuration has seven inputs three each for reference load voltage and source current respectively, and one for output of error (PI) controller. The tuning of fuzzy logic controller for outputting fundamental reference currents. The signals thus obtained are compared in a hysteresis band current controller to give switching signals. Fuzzy membership functions between 6 inputs as three phase currents and three phase voltages from input and two outputs as output voltage and current shown in below Fig.6. Fuzzy rules are written between error and change of error for one particular quantity based on that that given voltage or current as its output, like that 49 rules are framed. Similarly for other inputs of fuzzy editor framed out the rules. After better tuning the fuzzy membership functions at particular incidence that fuzzy gives an optimum solution.

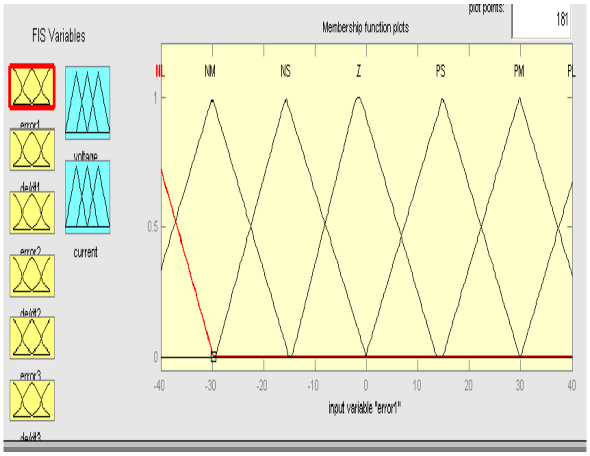

Fig. 6 Triangular membership functions

Table1. Linguistic Rule Table

Error / de/dt	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NM	NM	NM	NS	Z	PS
NS	NL	NM	NS	NS	Z	PS	PM
Z	NL	NM	NS	Z	PS	PM	PL
PS	NM	NS	Z	PS	PS	PM	PL
PM	NS	Z	PS	PM	PM	PM	PL
PL	Z	PS	PM	PL	PL	PL	PL

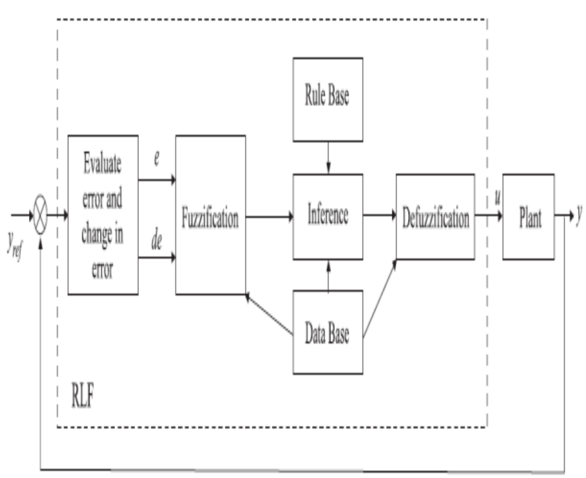

Fig.7 Basic Structure of Fuzzy Control System

6. SIMULATION RESULTS

For the verification of the performance of UPQC the system was simulated using Simulink Power System Blockset in Matlab. The analysis and design was done in continuous domain. However, to investigate the behaviour of the system, the UPQC system was simulated in discrete domain. All the compensators are implemented using equivalent discrete blocks. To observe the performance of shunt filter for voltage correction the shunt filter is switched on first, and then the series filter is switched on.

Table2:Simulation parameters of UPQC

Supply	3φ0Hz230V RMS, with 10% of 5th & 5% of 7th harmonics
Load	(150+j12.56)Ω
DC link inductance	150mH
DC link resistance	0.01Ω
LC filter	25μF, 1Ω,0.4mH
Sample time	1μs
Smootheni ng inductor	1mH
Line inductance	50μH
Line resistance	0.01Ω

The large data of source current, reference load voltage,power loss component and reference compensation current from conventional method are collected at a sample rate of 1μ sec and are stored in Matlab workspace. These data are used for fuzzy logic controller. The performance of UPQC using designed based on PID Controller and fuzzy logic controller is presented in Figs 8–15 for a non linear load derived using an uncontrolled diode bridge.

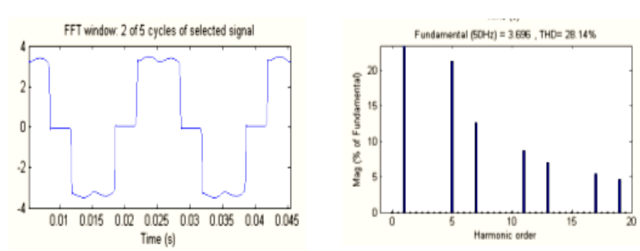

Fig.8 Load Current Harmonic Analysis for a system with UPQC and FLC

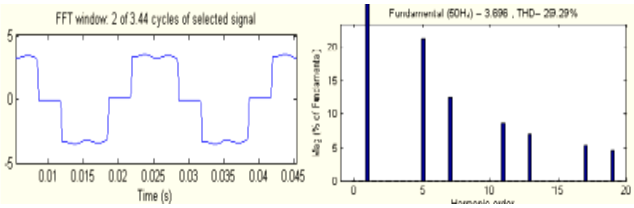

Fig.9 Load Current Harmonic Analysis for a system with UPQC and PID

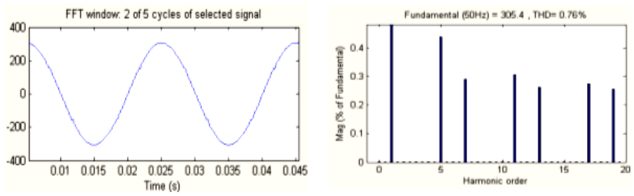

Fig.10 Source Current Harmonic Analysis for a system with UPQC and FLC

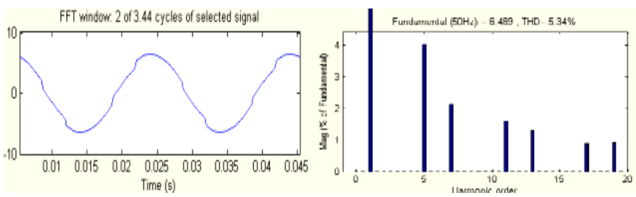

Fig.11 Source Current Harmonic Analysis for a system with UPQC and PID

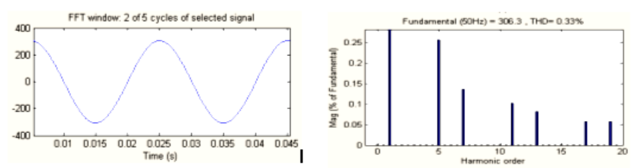

Fig.12 Source Voltage Harmonic Analysis for a system with UPQC and FLC

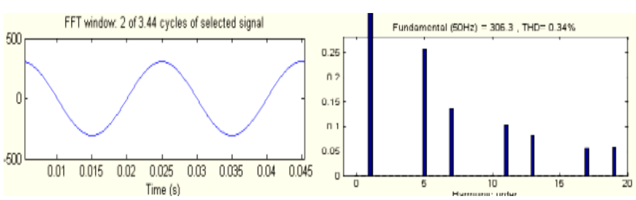

Fig.13 Source Voltage Harmonic Analysis for a system with UPQC and PID

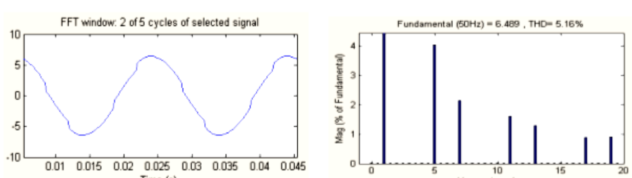

Fig.14 Load Voltage Harmonic Analysis for a system with UPQC and FLC

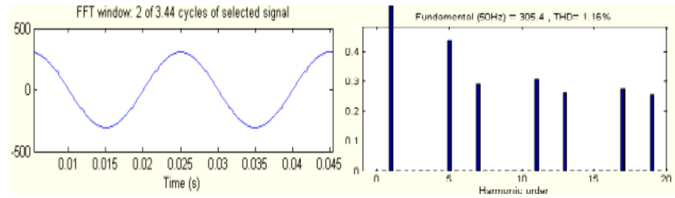

Fig.15 Load Voltage Harmonic Analysis for a system with UPQC and PID

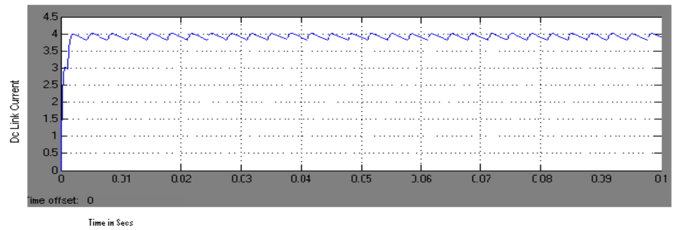

Fig.16 DC Link Current

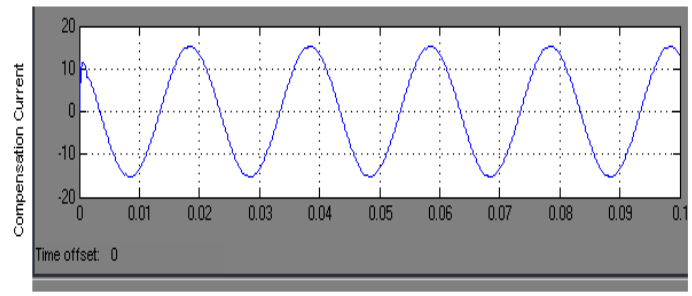

Fig.17 Compensation Current

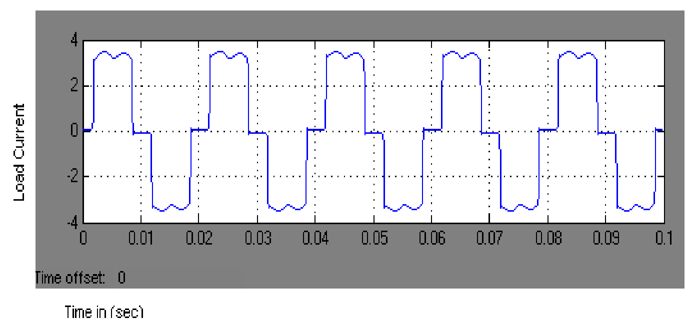

Fig.18 Load Current

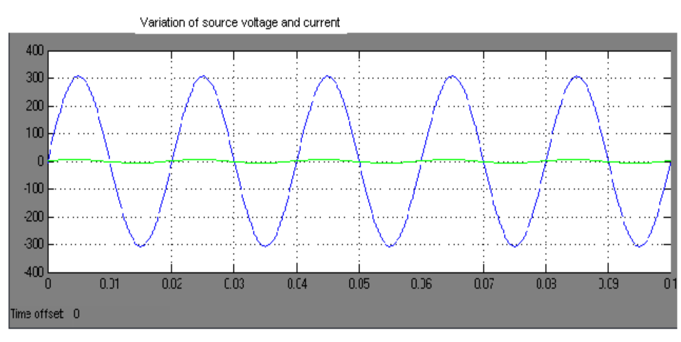

Fig.19 Variation of source voltage and current

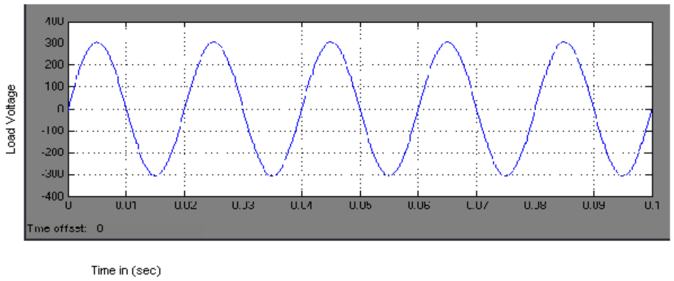

Fig.20 Load Voltage

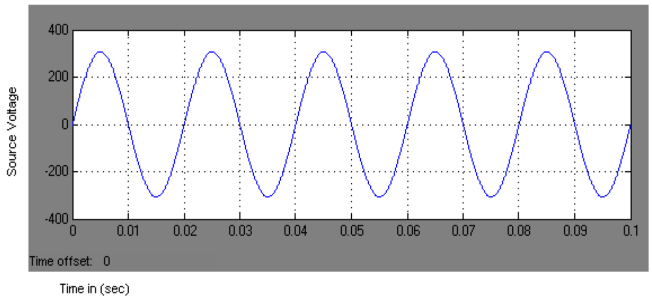

Fig.21 Source Voltage

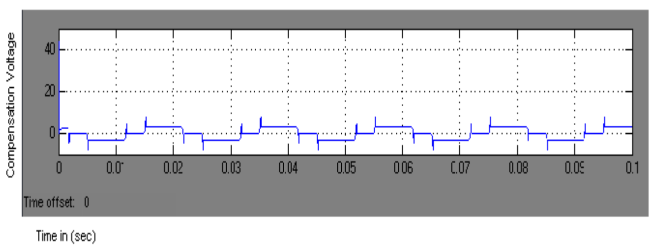

Fig.22 Compensation Voltage

From the above performance characteristics it is observed that the designed Fuzzy Logic controller perform satisfactorily. The shunt filter compensates for voltage harmonics and reactive power. Figs16 to 21 shows the performance of shunt filter and series filter for voltage harmonics, current harmonics, and reactive power compensation. The frequency

spectrum of load current as shown in Fig 8 gives the measure of harmonic content of source current before compensation which is 28.14%. and from Fig.9 the same analysis by PID which gives 29.29%. This is beyond the acceptable limits of IEEE 519 standard for current distortions in a distribution system. With the designed fuzzy logic controller the THD of source current improves to 0.76% shown in Fig.10 and the same analysis by PID 5.34% shown in Fig.11, which is well within the acceptable limit of IEEE standards. Similarly the series filter compensates for voltage harmonics present in the system, harmonic content of source voltage improves to 0.33% shown in Fig.12 the same from PID 0.34% shown in Fig.13. But Load voltage gives harmonic content 5.16% which is higher than the acceptable limit of IEEE 519 for voltage distortions in distribution system shown in Fig.14. the fuzzy Controller not only that the THD of source current improves, the control of dc link current smoothens which can be observed from its performance characteristic as shown in Fig 16, from Figs 17 to 21 gives the performance of shunt controller and series controller for voltage and current wave forms given for load source and compensation correspondingly .

7. CONCLUSIONS

UPQC performance mainly depends upon how accurately and quickly reference signals are derived. By using conventional Akagi's principle reference signals was derived. The simulated result shows that it has considerable response time for yielding effective compensation in the network. This may not be desirable in modern power system control. Using conventional compensator data, a fuzzy logic controller (FLC) is tuned with large number of data points. Then conventional compensator was replaced with fuzzy logic controller and simulated using Matlab/simulink for R-L load using uncontrolled rectifier. The simulation results have shown that the UPQC perform better with FLC proposed scheme eliminates both voltage as well as current harmonics effectively. It is also observed that the response time for derivation of compensation signals reduces significantly with improved accuracy.

8. REFERENCES

[1] Akagi, H. (1996) 'New trends in active power filter for power conditioning', *IEEE Transactions on Industrial Applications*, ov/Dec, Vol. 32, No. 6, pp.1312–1322.

[2] Chen, M.H.H. (2000) 'Modeling and controlling of unified power quality conditioners', *Proceedings of 5th International Conference on Advances in Power System Control, Operation and Management*, APSCOM 2000, Hong Kong, October, pp.431– 435.

[3] Elmitwally, A., Abdelkader, S. and EL-Kateb, M. (2000) 'Neural network controlled three-phase four-wire shunt active power filter', *IEE Proc.,-Gener. Trans. Distr*., March, Vol. 147, No. 2.

[4] Fujita, H. and Akagi, H. (1996) 'The unified power quality conditioner: the integration of series active filter and shunt active filters', *Proceedings on IEEE/PES Power Electronics Specialist Conferences*, June, pp.491–501.

[5] Grady, W.M., Samotyj, M.J. and Noyola, A.A. (1990) 'Survey of active power line conditioning methodologies', *IEEE Transactions on Power Delivery*, July, Vol. 5, No. 3, pp.1536–1542.

[6] Graovac, D., Katic, V., Rufer, A. and Kneevi Baldor, J. (2001) 'Unified power quality conditioner based on current source converter topology', *EPE Graz*, pp.1–9.

[7] [7] Gunther, E.W. and Mehta, H. (1995) 'A survey of distribution system power quality', *IEEE* G. O. Young, "editor),"*Transactions on Power Delivery*, January, Vol. 10, No. 1, pp.322–329.

[8] Jianjum, G.U., Dianguo, X.U., Hankui, L. and Maozhang, G. (2002) 'Unified power quality conditioner (UPQC): the principle, control and applications', *IEEE proceedings on Power Conversion Conference*, Osaka, Vol. 1, pp.80–85.

[9] Khadkikar, V., Aganval, P., Chandra, A., Bany, A.O. and Nguyen, T.D. (2004) 'A simple new control technique for unified power quality conditioner (UPQC)', *11th International Conference on Harmonics and Quality of*

Power, Lake Placid, NewYork, USA, Sept 12-15, pp.289–293.

[10] King, R.E. (1999) Computational Intelligence in Control Engineering, Marcel Dekker Inc, New York, pp.155–56.

[11] Singh, B., Kamal, A.H. and Chandra, A. (1999) 'A review of active filters for power quality improvement', *IEEE Transactions on Industrial Electronics*, October, Vol. 46, No. 5, pp.960–971.

[12] An Optimum UPQC with Minimum VARequirement and Mitigation of Unbalanced Voltage Sag by Y. Y. Kolhatkar_ S. P. Das in International Journal of Emerging Electric Power Systems, Volume 2, Issue 2 2005 Article 1

[13] UPQC Signal Detection Algorithm Studies Based on PSO-FUZZY by Hong Shen, Jianru Wan, Yingpei Liu, Chenhu Yuan, Guangye Li, 978-1-4244-2800-7/09/$25.00 2009 IEEE

[14] Unified Power Quality Conditioner (UPQC): the Principle, Control and Application by Gu Jianjun, Xu Dianguo, Liu Hankui, and Gong Maozhong, *0-1803-7* 156-9/02/$10.000 *2002* IEEE

[15] Control Strategies of UPQC: Time-Domain Approach by S. Chatterjee and N. P. Padhy , Fifteenth National Power Systems Conference (NPSC), IIT Bombay, December 2008

[16] J. Gu, D. Xu, H. Liu, M. Gong. Unified Power Quality Conditioner (UPQC): Principle, Control and Application. Power Conversion Conference, Vol.1, PCC-Osaka, IEEE 2002, 80-85

[17] Elmitwally, A., Abdelkader, S., and Elkateb, M.: 'Universal power quality manager with a new control scheme', IEE Proc. Gener.Transm. Distrib., 2000, 147, (3), pp. 183–189

[18] Control scheme for a universal power quality manager in a two- phase synchronous rotating frame by P. Zhu, X. Li, Y. Kang and J. Chen, IEE Proc.-Gener. Transm. Distrib., Vol. 151, No. 5, September 2004

[19] Han, B. Bae, B. Kim, H. Baek, S. "Combined operation of unified power-quality conditioner with distributed generation". *"Power Delivery, IEEE Transactions"* vol. 21, Jan.2006, pp330- 338

[20] Salehi, V. Kahrobaee, S. Afsharnia, S.,"Power Flow Control and Power Quality Improvement of Wind Turbine Using Universal Custom Power Conditioner". "Industrial Electronics, July 2006 IEEE International Symposium" ,vol.3, pp.1888-1892

Biographical notes:

Mr.R.V.D.Rama Rao received A.M.I.E graduation from I.E(India),Calcutta,India. The M.Tech Degree from J.N.T.U, Ananthapur.(with specialization in Power and Industrial Drives) in 1997and 2005 respectively. He is presently working as an Associate Professor in Narasaraopeta Engineering College, Narasaraopet, India and pursuing part-time Ph.D in J.N.T.U, Hyderabad, Andhra Pradesh. His areas of interests include Power Quality by FACTS Controllers,controllers like Conventional controllers, Fuzzy controllers, Neuro Controller Neuro- Fuzzy controllers, Power Electronics and Drives.

Dr. Subhransu Sekhar Dash received A.M.I.E graduation from I.E (India), Calcutta, India. The M.E Degree from U.C.E, Burla, Orissa, India,.(with specialization in Power Systems) and the Ph.D degree in Electrical Engineering from Anna University College of Engineering, Guindy, Chennai-25 in 1994, 1996 and 2006 respectively. He has published more number of Papers in National and International reputed Journals. He is presently working as Professor in SRM Engineering College, SRM University, Chennai, India and His areas of interests include FACTS, Power System operation, Control & Stability, Power Electronics & Drives and Intelligent controlling Techniques.