Mitigation of Current and Voltage Perturbations in a Power Distribution Network by Fuzzy Control of UPQC

Ramesh Babu Mutluri[1], Yatindra Gopal[2] , Suman Khichar

Abstract: In power quality, the current harmonics is the common problem and voltage sags are the severe. This paper presents voltage and current perturbations compensation by Unified Power Quality Conditioner in a power distribution system. The topology is based on a parallel active power filter and a series active power filter which share two DC link capacitors acting as 3-phase voltage source inverters. This paper proposed a new effective control system to reduce the voltage fluctuations like sag, swell conditions besides current and voltage harmonics isolation in distribution systems by unified power quality conditioner. The unified power quality conditioner can be used for improving power quality at the point of common coupling is simulated using proposed control approach. The performance is compared by applying proportional integral based, Fuzzy based unified power quality conditioner to a distribution system. The performance of this unified power quality conditioner has been assessed with a typical industrial load with realistic parameters provided by a contaminated distribution network. In the MATLAB/SIMULINK environment Dynamic model of the unified power quality conditioner is developed. Simulation results indicating the power quality enhancement in the system are presented with different supply and load.

Keywords: Power quality, unified power quality conditioner (UPQC), flexible AC transmission systems (FACTS), DVR & DSTATCOM, proportional integral (PI) controller, fuzzy controller.

1. Introduction

Because of their economic effects on both utilities and customers Power quality problems have gained a great attention nowadays. The Hysteresis Pulse width modulation (PWM)controls theory argument in relation to FACTS technology and Unified Power Quality Conditioner(UPQC) [1].In the current years a eminent term for advanced controllability is Flexible AC Transmission Systems FACTS in power systems through power electronic devices [1]-[5]. Numerous FACTS-devices have been introduced and commissioned for various requirements worldwide [2]-[4].The most prevalent are: phase-angle regulators, static VAR compensators, load tap changers, thyristor-controlled series compensators, static compensators, interphase power controllers and unified power flow controllers. The idea based on power-electronic strategy, which improve the value of transmission networks by increasing the use of their capacity is FACTS. Controllability is used to avoid cost intensive or landscape requiring extensions of power systems in most of the applications, for example like elevations or additions of substations and power lines and improved adaptation to varying operational conditions and improve the usage of existing installations[3]-[7]. FACTS-devices are increase of transmission capability, Voltage Control, Compensation of reactive power, power quality and stability improvement, conditioning of Power, mitigation of flicker and renewable interconnection with distributed generation. The source of harmonics, voltage and current problems are common industrial and commercial loads are of non-linear type. The suitable appliance to guard sensitive loads from short period voltage dips or swells is DVR but doesn’t mitigate load current harmonics, whose presence, consequences in low power factor, leads to voltage notch and reduced consumption of the distribution system. STATCOM device is commonly suppress harmonics of load current in addition to the control of reactive power but it doesn’t mitigate of voltage related problems [8]-[11]. UPQC gives mitigation for both voltage and current quality problems simultaneously. Two voltage source converters (VSCs) connected to a common dc bus which is acting as UPQC is presented in this work of paper. One VSC is connected in series with a distribution feeder, while the remaining one is connected in shunt with the same feeder. Common dc capacitor supplies the dc links of both VSCs. UPQC reduce the disturbances which consequence the process of sensitive load and compensate the swell, sag, voltage unbalanced, current, voltage harmonics and reactive component of power [12]-[16].

2. Design of UPQC

During the past few decades, the increase of non-linear loads, such as diode, thyristor rectifiers and cyclo-converters draw non-sinusoidal currents in to power system, thus causing to the of power quality degradation or industrial power system [5]-[6]. Particularly distortion of voltage and harmonics in the power systems have been serious issue. To get the solution nearly all power quality problems in recent research work have been done towards utilizing UPQC.

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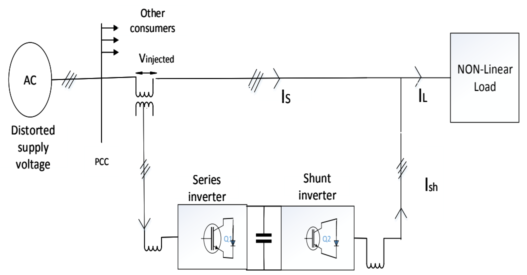

Fig.1. Basic Block Diagram of UPQC

Voltage source inverter which produces sinusoidal voltage with the frequency, amplitude and the phase decided by the control strategy as shown in fig .1. Based on the other non-linear loads connected at PCC the PCC voltage may be or may not be distorted. In this paper, it is supposed that PCC voltage is distorted. Two voltage source inverters sharing a common dc link are coupled back to back. One inverter is connected parallel with the load; it working as shunt APF to help in compensating harmonics of load current as well as to maintain voltage of dc link at constant level. The remaining inverter is connected in series with utility voltage by using series transformers and helps to maintaining the sinusoidal load voltage [7]-[8].The function of UPQC is reducing the disorders which effect the working of sensitive load, also able to compensate the swell, sag, unbalanced voltage, current, harmonics of voltage and reactive component of power voltage source inverters which are connected in shunt and series. Compensation voltage (V_f*) can be provided through the series inverter of UPQC and conditioning current (*i_f) through the inverter connected in shunt by instantaneous sampling of load current, source voltage with current by Controller. In a hysteresis type PWM current controller, the obtained reference currents are compared with output currents (i_{fa}, i_{fb} ,i_{fc})of shunt inverter[9]-[10]. To improve the accuracy of design, an appropriate controlling method has been Chosen to simulation and series and shunt inverters ratings has been calculated through loading calculations of these inverters applying phasor diagram.

3. Control strategy of UPQC

If the supply voltage is V_s, series compensation voltage, shunt compensation current are V_c, I_c and voltage and current of the load are V_L, I_L. The voltage of source may comprise negative, zero as well as components of harmonic. Per phase system voltage can be stated as [9]:

$$V_{sa} = V_{1pa}(t) + V_{1na} + \sum_{k=2}^{\infty} V_{ak}(t) \quad (1)$$

$$V_{sa} = V_{1p}\text{Sin}(\omega t + \theta_{1p}) + V_{1n}\text{Sin}(\omega t + \theta_{1n}) + \sum_{k=2}^{\infty} V_{ak}\ (k\omega t + \theta_{ka}) \quad (2)$$

Where V_{1pa} = fundamental frequency of positive sequence components,

V_{1na} = fundamental frequency of negative sequence components.

V_{1p} = amplitude of positive sequence voltage.

V_{1n} = amplitude of negative sequence voltage.

The last term of equation denotes the content of harmonics in the voltage.

$$V_{ca} = (V - V_{1p})\sin(\omega t + \theta_{1p}) - V_{1an}(t) - \sum_{k=2}^{\infty} V_{ak}(t) \quad (3)$$

The per phase load current of shunt active filter is expressed as [9]:

$$I_{al} = I_{1p}\sin(\omega t + \theta_{1p}) + I_{a1nl} + \sum_{k=2}^{\infty} I_{alk} \quad (4)$$

Equation (4) can be written as

$$I_{ca} = I_{la} - I_{ca} = I_{1p}\,\text{Sin}(\omega t + \theta_{1p})\,\text{Cos}(\phi_{1p}) \quad (5)$$

where ϕ_{1p} = initial phase of current ϕ_{1p} = ϕ_{1p} - θ_{1p}

When the output current of shunt-APF is kept to be equal to the component of the load current as the follow equation:

$$I_{ca} = I_{1p}\,\text{Cos}(\omega t + \theta_{1p})\,\text{Sin}(\theta_{1p}) + I_{a1nl} + \sum_{k=2}^{\infty} I_{alk} \quad (6)$$

In order to pay off harmonic current and demand of reactive power the shunt active filter should yield a current of the equation (6). Then the harmonic, reactive and negative sequence current will not stream into power source. Hence, source terminal current will be:

$$I_{ca} = I_{la} - I_{ca} = I_{1p}\,\text{Sin}(\omega t + \theta_{1p})\,\text{Cos}(\phi_{1p}) \quad (7)$$

This is a perfect harmonic free sinusoidal current in phase with voltage [1], [2], [7], [9].

Based on the abstraction of unit vector templates from the distorted input source the control strategy is designed[8]-[11]. These templates are then equivalent to unpolluted sinusoidal signal with unity (p. u) amplitude. The extraction of unit vector equal to 1/V_m. V_m is the peak amplitude of fundamental input voltage. The unit vector templates are generated by taking unit input vectors voltage to phase locked loop (PLL) with proper phase delay.

$$\begin{cases} U_a = \sin(\omega t) \\ U_b = \sin(\omega t - 120) \\ U_c = \sin(\omega t + 120) \end{cases} \quad (8)$$

Multiplying unit vector templates with the peak amplitude of fundamental input voltage explicate in equation (1) which gives the reference load voltage signals for series active pass filter to produce the essential gate signals. The UPQC complete control circuit is shown in the Fig.2. The generated error will be taken to a hysteresis controller in kHz for a motor drive. The term of duty cycle designates the share of 'on' time to the Regular interval or 'period' of time. The low duty cycle resembles to low power, because for most of the time the power is off. The reference load voltage signals are compared with measured load voltages [9]-[12].

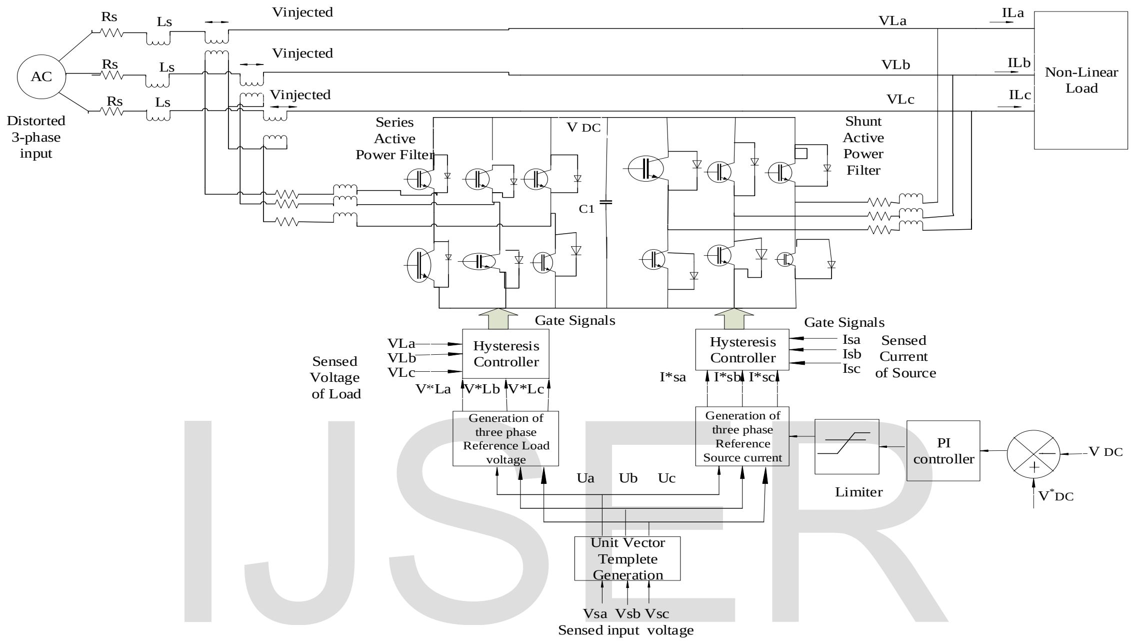

Fig. 2. Over all control circuit of UPQC

4. PI controller

PI control is required for non-integrating processes, sense any procedure that eventually returns to the same output given the same set of inputs and disturbances. This paper compares sag voltage with the reference voltage and error voltage is treated through PI. Controller output is converted to three phase through unit vector generation, and then it is fed into Pulse Width Modulation (PWM) generator to provide gate pulses to APF. This can be able to inject the required voltage for the mitigation of voltage Perturbations [5], [8], [13]. The gain values *p* and *i* are chosen as K_p=0.2 and K_i= 1.5.

5. Fuzzy logic controller

Fuzzy logic is very near in spirit to human thinking and natural language. Controllers based on fuzzy logic give the linguistic strategies control conversion from expert knowledge in automatic control strategies [9], [14]. The schematic structure of a fuzzy logic controller is shown in Fig 3. A set of linguistic rules determines the basic control action by system. Since the numerical variables are converted in to linguistic variable, mathematical modeling is not required in FLC.

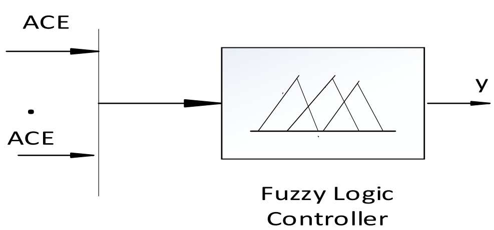

Fig. 3. Fuzzy Logic Controller

Linguistic rules of fuzzy controller

FLC provides a simple way to arrive at a definite conclusion depending upon blurred, ambiguous, imprecise, noisy, or missing input data. The linguistic rules of FLC are mention in table 1

TABLE 1
REPRESENTATION OF FUZZY RULES

de / e	NL	NM	NS	Z	PS	PM	PL
NL	NL	NL	NL	NL	NM	NS	Z
NM	NL	NS	Z	NM	PS	PM	PM
NS	NL	NS	Z	NM	PS	PM	PL
Z	NL	NL	NL	NS	Z	NM	PS
PS	NL	NS	Z	NM	PS	PM	PL
PM	NS	NS	Z	NM	PS	PM	PL
PL	NL	NS	Z	PS	PS	PM	PL

Similarly, according to the various combination of inputs and the output all other rules can be written as NL- Negative Low, NM- Negative Medium, NS- Negative Small, Z- Zero, PL- Positive Large, PM- Positive Medium, PS- Positive Small.

Fuzzy logic controller removes the disadvantages of PI controller [11], [15]. The PI controller difficulty is feedback system, with constant parameters, and direct information of the process is not available.

In this paper, an advanced control strategy, FLC is realized along with UPQC for voltage correction through Series APF and for current regulation by Shunt APF [16]-[19]. Fig. 4 and Fig. 5 show the membership function of input 1 and input 2 of FLC.

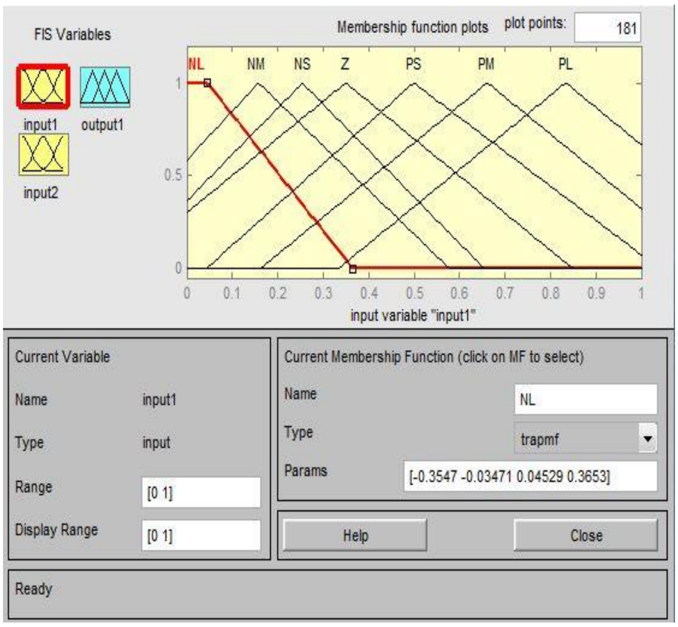

Fig. 4. Membership function plots for ACE (input 1)

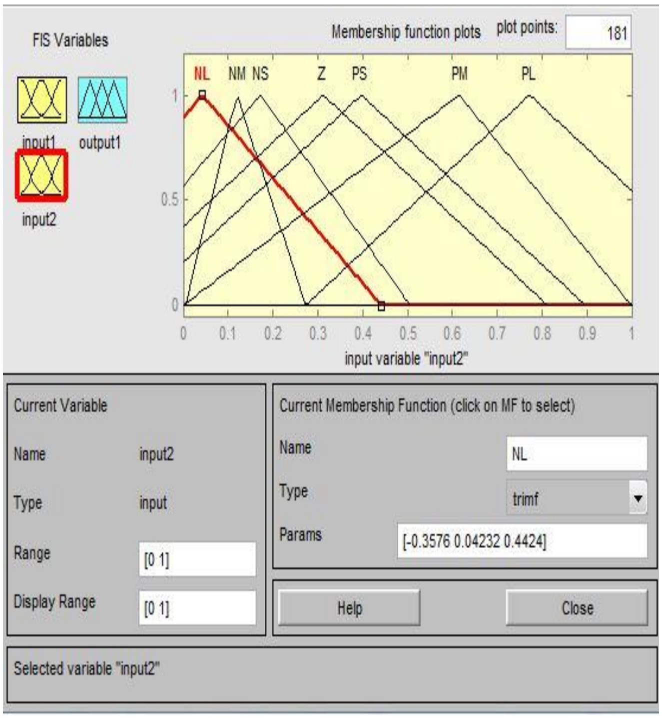

Fig. 5. Membership function plots for derivative of ACE (input 2)

Membership function of output for FLC is shown in Fig. 6 and the FLC rule viewer shown in Fig. 7. Trapezoidal membership functions are taken in FLC to define rules. All the rules can be seen in rule viewer shown in Fig.7

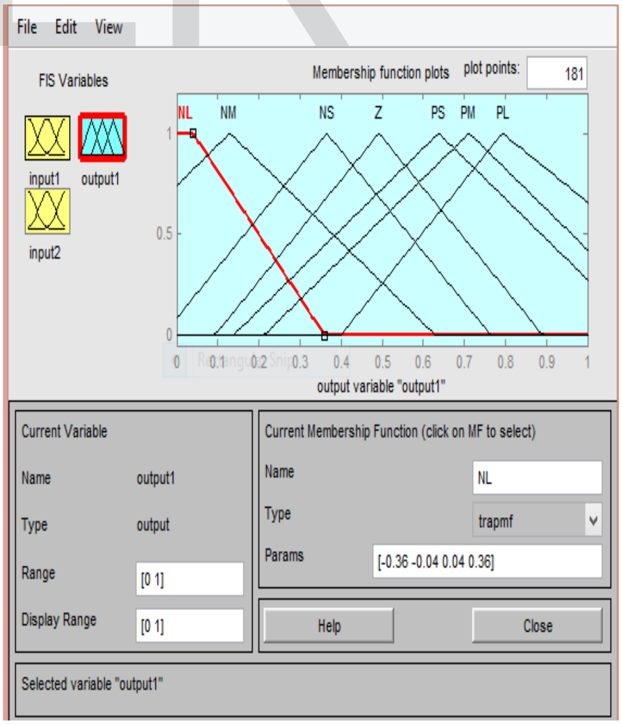

Fig. 6. Membership function plots for output

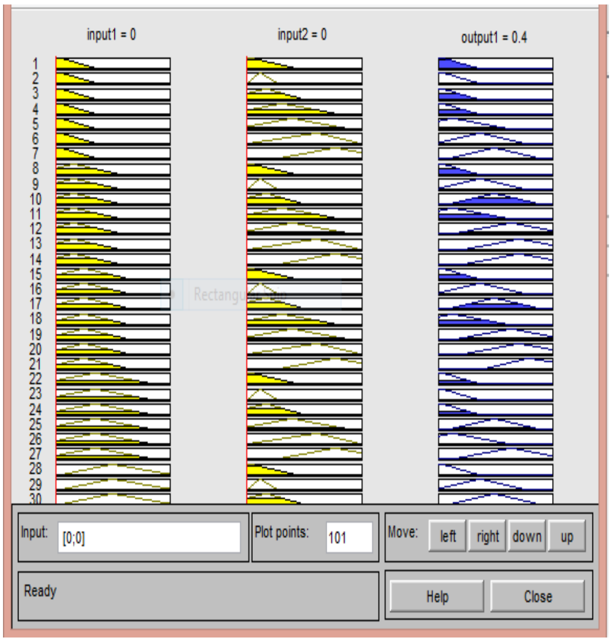

Fig.7. Rule viewer of FLC

6. Simulation and results discussion

The proposed Fuzzy controller for UPQC alleviating both voltage and current Perturbations is implemented which compensated voltage, current quality problems simultaneously and results are shown. Table 2: show the used of design simulated parameter of UPQC.

TABLE 2

THE FOLLOWING DESIGN PARAMETERS ARE USED FOR SIMULATION OF UPQC

S. no	Source voltage	Line-Line(rms)	415V,50Hz
1	DC Link	Capacitor	5500 μF
		Reference Voltage	750Volts
2	Shunt Compensator	Filter L,C	2200mH,1400μF
3	Series Compensator	Filter L,C	2:5, 10kva
		Transformer(n1;n2), kva	
4	Load	Nonlinear load P,Q	100kw,2460kvar

By using the different parameters mentioned in the Table 2, voltage and current problems are created in the source which mitigated later by UPQC.

The three-phase supply voltage for non-linear R-L load where Sag and Swell are created from 0.1s to 0.15s and 0.15s to 0.2s is shown Fig. 8.

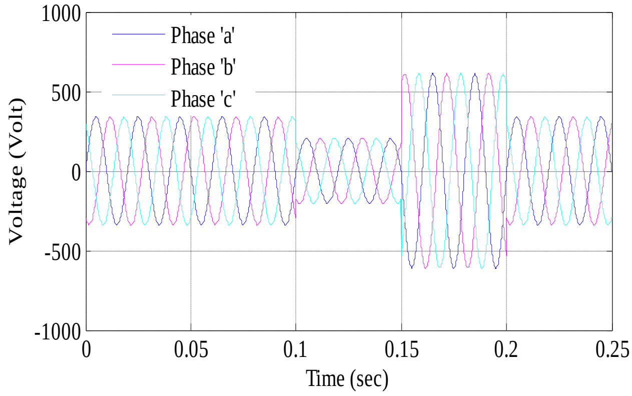

Fig. 8. Supply voltage for non-linear R-L load

Voltage (Vpcc) where sag and swell are mitigated at PCC is shown in Fig.9.The sag and swell which is created from0.1s to 0.15s and 0.15s to 0.2s is mitigated by using UPQC with PI controller.

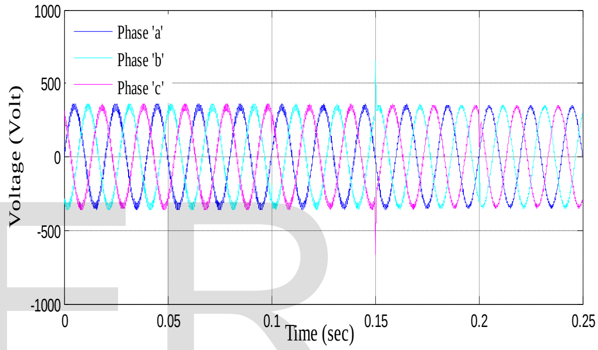

Fig. 9. PCC voltage with PI controller

Source current which is affected by voltage sag and swell in supply voltage is shown in the Fig.10.Three phase currents are shown separately for a non-linear load.

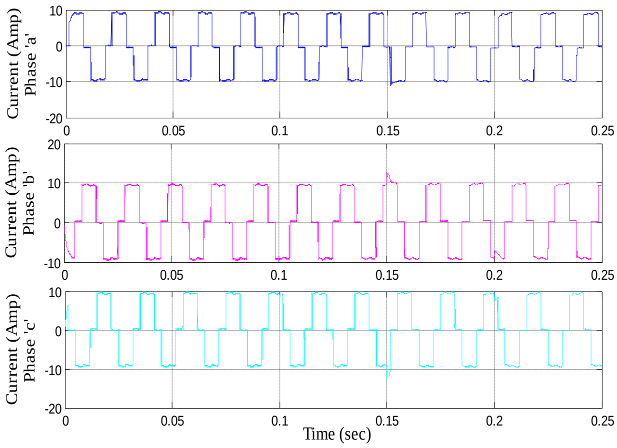

Fig. 10. Source current with PI controller for phase 'a', phase 'b' and phase 'c'.

PCC current which is improved by using UPQC is shown in the Fig.11.The effect of sag and swell which is created from 0.1s to 0.15s and 0.15s to 0.2s is mitigated by using UPQC with PI controller along with improvement in current waveform

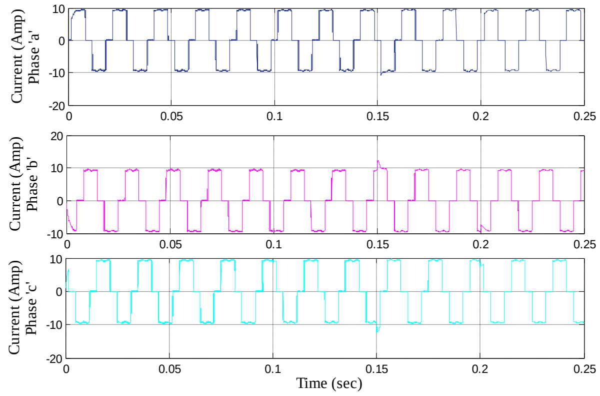

Fig. 11. PCC current with PI controller

Capacitor charging with PI controller is shown in the Fig. 12. If we observe charging process from 0.15 sec to 0.20 sec 250 volts charged with in 0.05 sec of time.

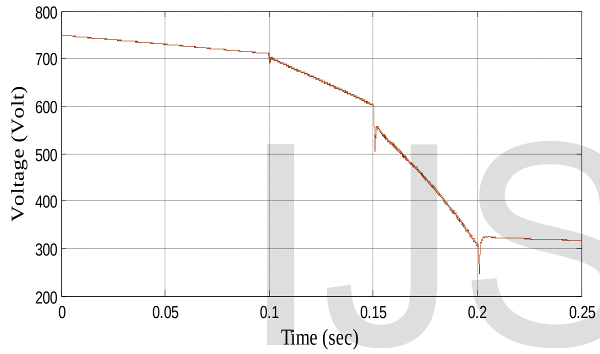

Fig. 12. Capacitor charging voltage with PI controller

Point of common coupling voltage (Vpcc) with fuzzy controller is shown in the Fig.13. The voltage sag and swell are mitigated in the voltage at PCC by using fuzzy logic controller. The voltage wave form is nearly modified to Sinusoidal.

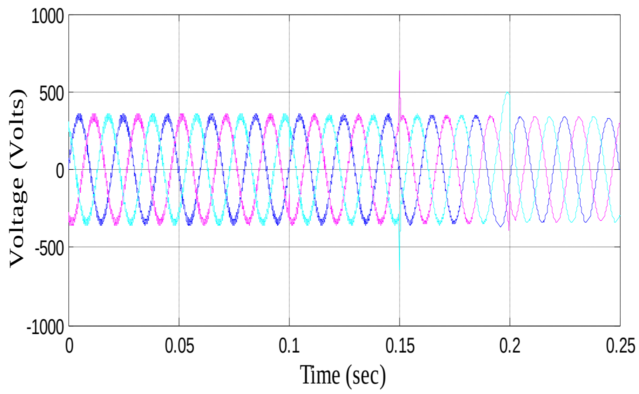

Fig. 13 PCC voltage with fuzzy controller

PCC current which is improved by using UPQC with fuzzy logic controller is shown in the Fig.14.

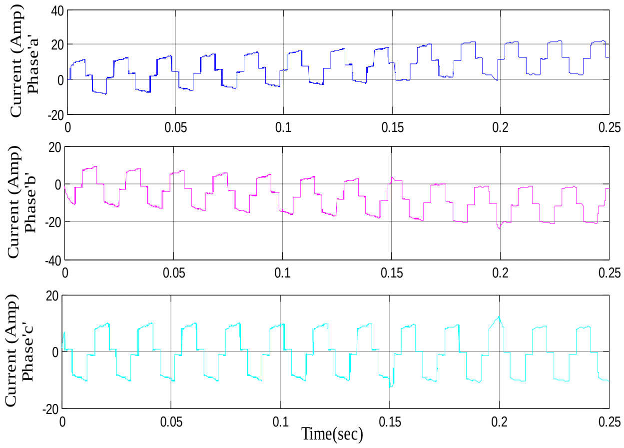

Fig. 14. PCC current with fuzzy controller

Capacitor charging with fuzzy controller is shown in the above Fig.15. If we observe charging process from 0.15sec to 0.20sec 500volts charged with in 0.05sec. Hence Charging process is faster by using fuzzy controller when compared to PI controller.

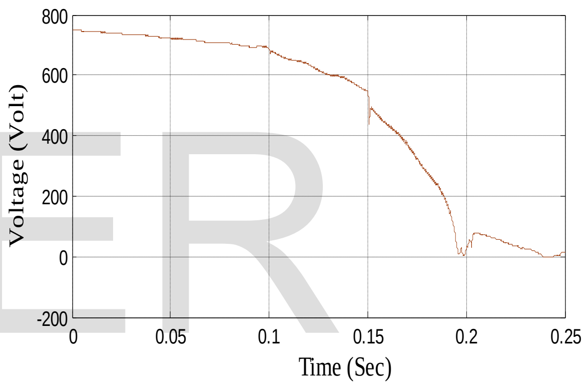

Fig. 15. Capacitor charging with a fuzzy controller

The success of the proposed FLC system is proven by comparing the proposed control strategy with conventional PI controller.

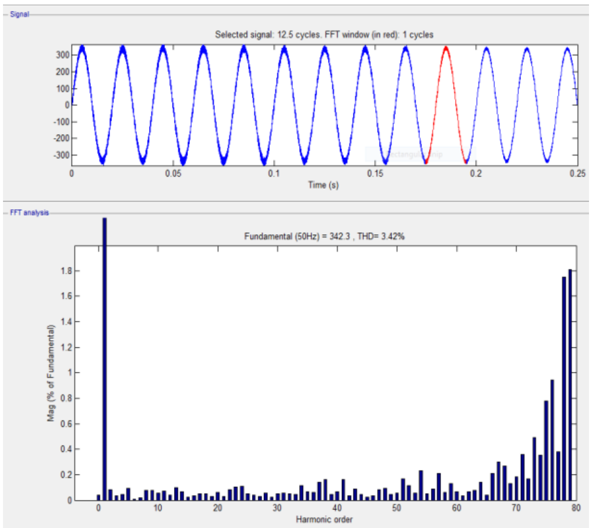

Fig. 16. FFT analysis of Vpcc with PI

FFT analysis of voltage at PCC by using PI controller is Shown in the above Fig.16.THD is obtained as 3.42%. This is within allowed limits [19], [20]. FFT analysis of current at PCC by using PI controller is Shown In the above Fig.17. THD is obtained from Ipcc with PI is 30.31%.

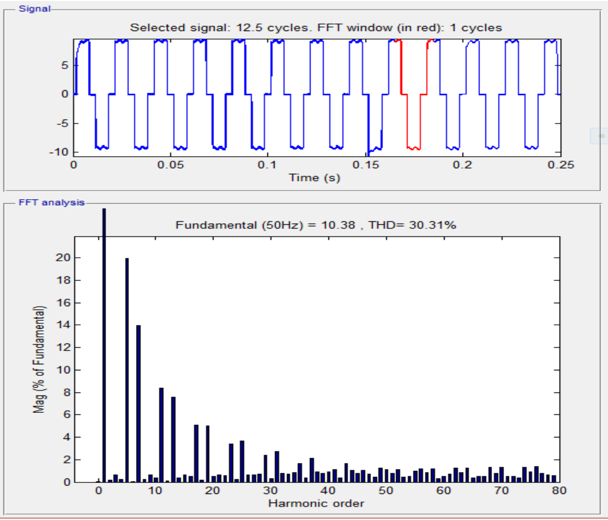

Fig.17. FFT analysis of Ipcc with PI

FFT analysis of voltage at PCC by using Fuzzy controller is shown in the Fig.18. THD is obtained as 2.06% which is less when compared with PI compensation [20] - [22].

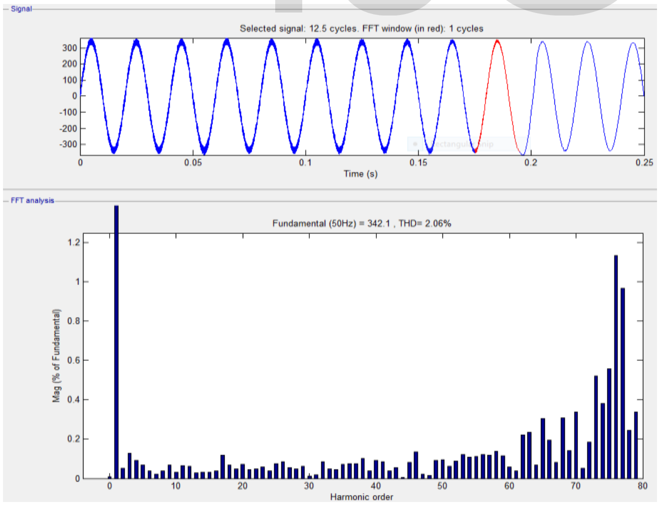

Fig.18. FFT analysis of Vpcc with Fuzzy

FFT analysis of current at PCC by using Fuzzy controller is shown In the Fig.19. THD is obtained as 29.78% which is less when compared with PI compensation.

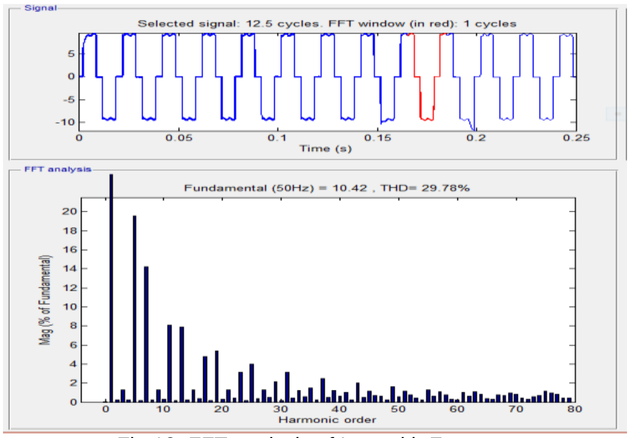

Fig.19. FFT analysis of Ipcc with Fuzzy

The performance comparison results of UPQC with PI and Fuzzy logic controller is shown in Table 3.

TABLE 3
PERFORMANCE COMPARISON

S.No	Parameter	With PI controller	With Fuzzy controller
1	PCC Voltage THD	3.42%	2.06%
2	PCC Current THD	30.31%	29.78%
3	Capacitor Charging	Slow charging	Fast charging

From the Table 3, it can be observed that there is considerable decrease in the THD of both voltage and current by using FLC compared to PI controller. This conforms the superiority of proposed FLC.

7. Conclusions

Power quality in the distribution system can be improved by Custom power devices like DVR, D-STATCOM, and UPQC. There is an option to select particular custom power device with specific compensation based on the power quality problem at the load or at the distribution system. The combination of series and shunts APF is Unified Power Quality Conditioner (UPQC), which compensates supply voltage and load current faultiness in the distribution system. In this paper Unified Power Quality Conditioner (UPQC) is designed and simulated through hysteresis control theory with both PI, Fuzzy controllers .THD in PCC voltage and current are reduced by using fuzzy controller than by using PI controller by bringing down THD in voltage at PCC from 3.42% to 2.06% with current at PCC from 30.31% to 29.78%.If we observe capacitor charging process from 0.15 sec to 0.20 sec 250 volts charged with in 0.05 sec of time by using PI controller where as by using Fuzzy controller it is observed that charging process from 0.15 sec to 0.20 sec 500volts charged with in 0.05sec.Hence Charging process is faster by using fuzzy controller when compared to PI controller. By stabilizing DC link voltage in a improved way than the PI controller fuzzy controller balances the power between series and shunt inverters. In the MATLAB/SIMULINK environment dynamic model of the UPQC is developed and the simulation results confirming the power quality enhancement in the system.

8 References

[1] A. Teke, L. Saribulut, and M. Tümay, A Novel Reference Signal Generation Method for Power-Quality Improvement of Unified Power-Quality Conditioner, IEEE Transactions on Power Delivery, Vol. 26, No. 4, pp.2205-2214, October 2011.

[2] V. Khadkikar, Enhancing Electric Power Quality Using UPQC: A Comprehensive Overview, IEEE Transactions on Power Electronics, vol. 27, No. 5, pp. 2284-2296, May, 2012.

[3] H. R. Mohammadi, A. Y. Varjani, and H. Mokhtari, Multi converter unified power quality conditioning system MC-UPQC, IEEE Transactions Power Delivery, vol. 24, no. 3, pp. 1679–1686, Jul. 2009

[4] A. K. Jindal, A. Ghosh, and A. Joshi, Interline unified power quality conditioner, IEEE Transactions Power Delivery, vol. 22, no. 1, pp. 364–372, Jan.2007.

[5] K. S. Ravi Kumar, S.V.A.R.Sastry, "Application of PI,fuzzy logic and ANN,in improvement of power quality using UPQC" IJCSET vol. 1, Issue 5,pp.214-217, june 2011.

[6] I. Axente, N. G. Jayanti, M. Basu, and M. F. Conlon, A 12 kVA DSP controlled laboratory prototype UPQC capable of mitigating unbalance in source voltage and load current, IEEE Transactions Power Electron., vol. 25, no. 6, pp. 1471–1479, Jun. 2010.

[7] Y. Y. Kolhatkar and S. P. Das, Experimental investigation of a singlephase UPQC with minimum VA loading, IEEE Transactions Power Delivery, vol. 22, no. 1, pp. 373–380, Jan. 2007.

[8] G. Jayaraju, M. R. Babu, K G. Krishna, Hysteresis Control of Unified Power Quality Conditioner for Current and Voltage Perturbations Compensation in A Power Distribution Network, International Journal of Engineering Research & Technology, Vol. 2, no. 9, pp.1-6, September-2013.

[9] S. Shankar and A. Kumar, "Fuzzy based unified power quality conditioner, International Conference on Power, Signals, Controls and Computation (EPSCICON), pp.8 – 10 January, 2014.

[10] R. Bhavani, Dr. N. R. Prabha, C. Kanmani, Fuzzy Controlled UPQC for Power Quality Enhancement in a DFIG based Grid Connected Wind Power System, International Conference on Circuit, Power and Computing Technologies, pp.1-7, 2015

[11] R. Rezaeipour and A. Kazemi, Review of novel control strategies for UPQC, International Journal of Electrical and Power Engineering, vol. 2, pp. 241–247, 2008

[12] A. Eltnitwally, S. Abdelkader, and M. Elkateb, Universal power quality manager with a new control scheme, Proc. Inst. Elect. Eng. Gen. Transm. Distrib, vol. 147, no. 3, pp. 183–189, 2000.

[13] L. M. Tolbert, F. Z. Peng, and T. G. Habetler, A multilevel converter based universal power conditioner, Transactions Industry Applications, vol. 36, no. 2, pp. 596–603, Mar./Apr. 2000.

[14] N. G. Jayanti, M. Basu, M. F. Conlon, and K. Gaughan, Rating requirements of the unified power quality conditioner to integrate the fixed-speed induction generator-type wind generation to the grid, Inst. Eng. Technol. Renew. Power Gen., vol. 3, no. 2, pp. 133–143, 2009.

[15] K. Vadirajacharya, P. Agarwal, and H. O. Gupta, Performance evaluation of CSI-based unified power quality conditioner using artificial neural network, International Journal of Electronics, vol. 1, no. 1, pp. 17–32, 2008.

[16] A. K. Jindal, A. Ghosh, and A. Joshi, The protection of sensitive loads from interharmonic currents using shunt series active filters, Electric Power System Research., vol. 73, no.2 pp. 187 196, 2005.

[17] V. Khadkikar and A. Chandra, A new control philosophy for a unified power quality conditioner (UPQC) to coordinate load-reactive power demand between shunt and series inverters, IEEE Transactions Power Delivery, vol. 23, no. 4, pp. 2522–2534, Oct. 2008.

[18] IEEE Recommended Practices and Requirements for Harmonic Controlin Electrical Power Systems, IEEE Standard 519-1992.

[19] IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Standard 1547-2003.

[20] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. New York: Institute of Electrical and Electronics Engineers, 2000

[21] M. Forghani and S. Afsharnia, Online wavelet transform-based control strategy for UPQC control system, Transactions Power Delivery, vol.22, no. 1, pp. 481–491, Jan. 2007.

[22] M. George, "Artificial intelligence based three-phase unified power quality conditioner, Journal of Computational science, vol. 3, pp. 465–477, 2007.