Assessment and Simulation of UPQC System

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Abstract

Power quality is always a major factor to be considered, any power related problems is compromised by a power quality concern. Power quality is characterized by parameters that express continuity of service, variation in voltage magnitude, transient voltage and currents, harmonic content in waveform. A power quality mitigating device that deals with current at load side and supply voltage related problems by unified power quality conditioner (UPQC). This paper presents a review on UPQC where UPQC system can improve the power quality at the point of common coupling on power distribution systems under unbalanced and distorted load conditions and the simulation results based on Matlab/Simulink.

Key words — Active power filter (APF), harmonics, phase locked loop (PLL), power quality (PQ), Total harmonic distortion (THD), unified power-quality conditioner (UPQC).

1. Introduction

The "Power Quality" is most important word of any power delivery system today. Ignorance of quality, power affects electricity consumers in many ways. The problems arising due to lack of power quality can cause loss of production, frequent damage of equipment or appliances, increased power losses, interference with communication lines, reliability and so forth. The wide spread use of power electronics based equipment has produced a significant impact on quality of electric power supply by generating harmonics in voltages and currents. Therefore, it is very important to maintain a high standard of power quality [1]. Unified power quality conditioner is one of the solutions which were widely studied by many researchers as an eventual method to improve power quality of power supply at electrical distribution. The function of unified power quality conditioner is to compensate supply voltage flicker/imbalance, reactive power, negative sequence current, and total harmonic distortions (THD)[2].

In other words, the UPQC has the capability of improving power quality at the point of common coupling (PCC) which is the point of installation on power distribution systems. Therefore, the UPQC is expected to be one of the best solutions to large capacity loads sensitive to supply voltage flicker/imbalance. The UPQC is a facts device which is the combination of a series active power filter (APF) and shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link. The UPQC is able to maintain the load voltage as long as there is enough energy in the dc link capacitor, which is charged by the shunt APF.

Since UPQC is combination of both series APF and shunt APF it combines their compensation characteristics where shunt APF is usually connected across the loads to compensate for all current-related problems such as the reactive power compensation, power factor improvement, current harmonic, compensation, and load unbalance compensation whereas the series APF is connected in a series with the line through series transformers. It acts as controlled voltage source and can compensate all voltage related problems, such as voltage harmonics, voltage sag, voltage swell, flicker, etc.[2]

This paper is arranged as follows: part 2 describes about UPQC and its classification. Part 3 describes about working principle of UPQC. A digital simulation study and its results are presented in part 4 and 5. Part 6 concludes the paper

2. Assessment of UPQC

The paper is classified into A) physical structure of the UPQC, B) types of converter (current or voltage source), C) supply system (single-phase two-wire, three-phase three-wire and four-wire), D) System configuration, E) Control Strategies. Besides the assessment of UPQC, the paper also presents the simulation results of series filter and shunt filter (with PI and fuzzy controller).

A) Physical Structure of UPQC:

UPQC is a power electronic device that is employed in the distribution system to mitigate several power quality problems related with voltage and current simultaneously therefore it is multi-functioning device that compensate various voltage disturbances of the power supply, to correct voltage fluctuation and to prevent harmonic load current from entering the power system. UPQC consists of two voltage source converters connected in shunt and series cascaded by a common DC bus.

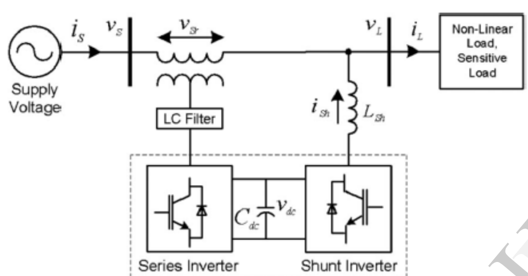

Fig-1: UPQC general block diagram

The components of UPQC are series and shunt converters, DC capacitors, low pass filters and coupling transformer. The key components of the system are:

(1) Two active power filters, one connected across the load which acts as shunt active power filter and other connected in series with the line is the series active power filter.
(2) Shunt coupling inductor lsh is used to interface the shunt inverter of the network. It also helps in smoothness of the current wave shape. Sometimes an isolation transformer is utilized to electrically isolate the inverter from the network.
(3) A common DC link that can be formed by using a capacitor or an inductor the DC link is realized using a capacitor which interconnects the two active power filters and also maintains self supporting DC bus voltage across it.

B) Types of Converters:

Current source inverter (CSI) shares a common energy storage inductor Ldc to form the DC link. The DC current in the inductor is regulated such that average input power is equal to the average output power plus the power losses. The CSI based UPQC is not popular because of higher losses, more cost.

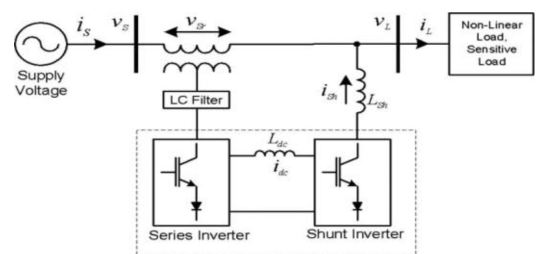

Fig. 2 CSI-based UPQC system configuration

Voltage source inverter(VSI) shares a common energy storage capacitor Cdc the advantages offered by VSI over CSI topology include lighter in weight, cheaper, capability of multilevel operation and flexible overall control.

C) Supply System:

The voltage related power quality problems are similar for both single and three phase systems except an additional voltage unbalance compensation needed in case of three phase system. For a single phase system, the load reactive current and current harmonics are major issues which are considered.

In case of three phase three wire system one need to consider current unbalance apart from reactive and harmonic current. Further there is three phase four wire system which requires an additional neutral current compensation.

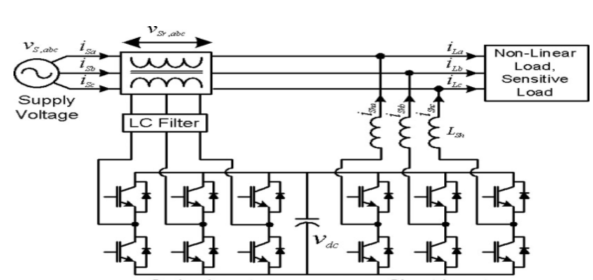

Fig. 3: 3P3W UPQC.

D) System Configuration:

(1) Right and Left shunt UPQC (UPQC-R and UPQC-L): UPQC has two back-to-back inverters it can be classified based on the placement of shunt inverter w.r.t to series inverter. The shunt inverter can be located either on the right (UPQC-R) or left (UPQC-L). Among two configurations UPQC-R is commonly used. In UPQC-R the currents that flow through series transformer is mostly sinusoidal irrespective to the nature of load current on the system (provided that shunt inverter compensate current harmonics, reactive current, unbalance etc.)

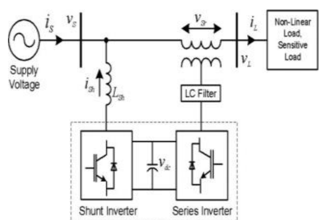

Fig 4:UPQC-L

(2) UPQC Interline: The two inverters of the UPQC are connected between the two distribution feeders. With such configuration simultaneous regulation of both the feeder voltages are achieved. Limitations are the current related problem could be effectively compensated on the feeder in which the inverter is connected in shunt. (UPQC-I).

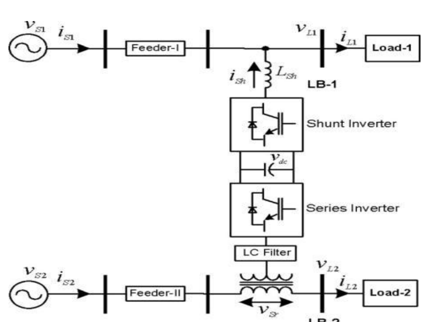

Fig 5:UPQC-I

(3)Multi converter UPQC: For improving the system performance by considering additional third converter unit to support DC bus (MC-UPQC).

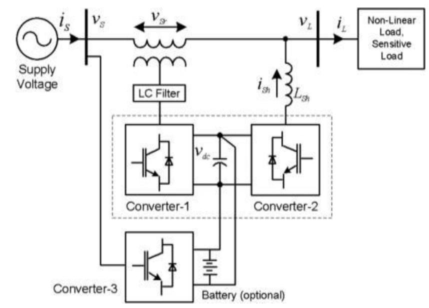

Fig 6**:** UPQC-MC

(4) Distributed Generators Integrators with UPQC: Solar and wind energies are emerging as alternate sources of electricity. The UPQC can be integrated with one or several distributed generation (DG) systems. The output of DG system is connected to DC bus of the UPQC. UPQC-DG system configuration to the loads connected to PCC in addition to the voltage and current power quality problem compensation. Additionally a battery can be connected to the DC bus, such that the excess DG generated power can be stored and used as back up can be regulated. Limitations increase of overall circuit, complexity and cost.

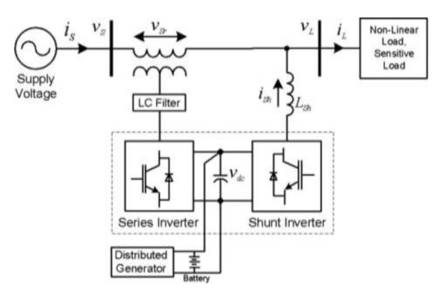

Fig 7:UPQC-DG

E) Control Strategies:

Control strategy plays the most significant role in any power electronic based UPQC system. Control strategy which decides the behaviour and desired operation of a particular system. The UPQC control strategy determines the reference signals (current and voltage) and thus decides the switching instants of inverter switches, such that the desired performance can be achieved.

Compensating commands are based on two types of domain methods (1) Frequency Domain and (2) Time

Domain methods. Frequency Domain methods are based on (FFT) is not popular due to large computation time and delay in calculating FFT. Control methods of UPQC in the time domain are Balanced energy method, Synchronous detection algorithm, Notch filter based controlling method but mostly used of UPQC are (a) Instantaneous active and reactive power or p-q theory (b) Synchronous reference frame method or d-q theory.

3. System Description

Reference Signal Generation:

Reference currents and voltages are generated using Phase Locked Loop (PLL) .where PLL is an accurate and fast detection of phase angle, amplitude and frequency of the utility voltage is essential to assure the correct generation of reference signals and to cope with the standard requirements.

The control strategy is based on the extraction of unit vector templates from the distorted input supply. These templates will be then equivalent to pure sinusoidal signal with unity (pu) amplitude. The three phase distorted input source voltage at PCC contains fundamental component and distorted component. To get unit input voltage vectors Vabc, the input voltage is sensed and multiplied by gain equal to 1/Vm, where Vm is equal to peak amplitude of fundamental input voltage. The unit input vector templates are generated

$$\left\{\begin{matrix} Va = \sin(\omega t) \\ Vb = \sin(\omega t - 120) \\ Vc = \sin(\omega t + 120) \end{matrix}\right\} \quad (1)$$

Multiplying the peak amplitude of fundamental input voltage with unit vector templates of eq(1) gives the reference load voltage signals

V*abc=VmVabc (2)

In order to have distortion less load voltage,the load voltage must be equal to these reference signals. The measured load voltages are compared with reference load voltage signals. The error generated is taken to hysteresis controller to generate the required gate signals for series inverter. The unit vector template can be apllied for shunt inverter to compensate the harmonic current generated by non linear load.the shunt inverter is used to compensate for current harmonics as well as to maintain the Dc link voltage at constant level. to achieve the above mentioned task the DC link voltage. A PI controller then process the error. The output signal from the PI controller is multiplied with unit vector templates of eq(1) giving reference source current signals. The source current must be equal to this reference signal. In order to follow this reference current signal, the three phase source currents are sensed and compared with reference current signals. The error generated is processed by hysterisis current controller with suitable band, generating gating signals for shunt inverter.

Hysteresis Controller:

Hysteresis is a feedback control method. Where the motor value track the reference value within a hysteresis band. Controller generates the sinusoidal reference value of desired magnitude and frequency that is compared with the actual motor line value. If the value exceeds the upper limit of the hysteresis band, the upper switch of the inverter arm is turned off and lower switch is turned on. As a result, the value starts to decay. If the value crosses the lower limit of the hysteresis band, the lower switch of the inverter arm is turned on. As a result, the value gets back into the hysteresis band. Hence the actual value is forced to track the reference value with Hysteresis Band(HB). The status of the switches is determined according to the error. When the value is increasing and the error exceeds a certain positive value, the status of the switches changes and the value begins to decrease until the error changes again. Compared with linear controllers, the non linear one based on hysteresis strategies allow faster dynamic response and better robustness w.r.t variation of the non-linear load.

Voltage regulator:

1. PI regulator:

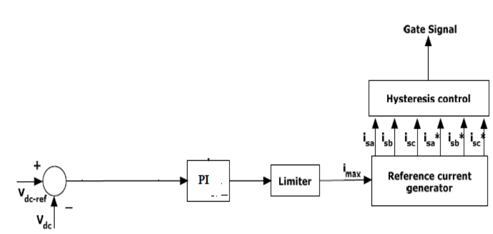

Fig: 8. PI controller circuit

The internal structure of control circuit consists of PI controller, limiter and 3-phase sine wave generator for reference current and switching generation.

The error signal is then processed through PI controller, which contributes to the zero steady state error in tracking the reference current signal.

The output of PI regulator will give active magnetizing current I_m expressed for nth sampling is shown in equation (3).

Im(n)=Im(n-1)+KpVdc(Vderr(n)-Vderr(n-1))+KIVdcVderr(n)

Where $\left.\begin{matrix} Kp = \text{propotional gain} \\ Ki = \text{integral gain} \end{matrix}\right\}$ of DC voltage (3)

The output signal from PI controller is multiplied with unit sine vectors in order to produce reference currents I_a^*, I_b^*, I_c^*, shown in following equations (4)-(5).

From PI gives magnetizing current

I*a =Im Va =Im sinθ

I*b=Im Vb=Im sin($\theta - 2\pi/3$) (4)

I*c=Im Vc=Im sin($\theta + 2\pi/3$)

Reference currents I*a, I*b, I*c are compared to actual currents (Ia, Ib, Ic)

Iaerr= I*a-Ia

Iberr= I*b-Ib (5)

Icerr= I*c-Ic

This current error signal is given to the hysteresis current controller. This error is compared to hysteresis band which gives the error signal decides the operation of converter switches. In this current control circuit configuration, the grid currents are made follow the sinusoidal reference current, with in a fixed hysteretic band. If the current exceeds the upper limit of HB, the upper switch of the inverter arm is turned off and lower switch is turned on and vice versa if current exceeds the lower limit.

2. Fuzzy logic controller:

Fuzzy systems are to be precisely defined and fuzzy control is a special kind of non linear control that also will be precisely defined. In the literature, there are two kinds of justification for fuzzy theory. They are:

1. The real world is too complicated for precise descriptions to be obtained; therefore approximation (fuzziness) must be introduced in order to obtain a reasonable, yet trackable model.

2. As we move into information era, human knowledge becomes more important. We need a theory to formulate human knowledge is a systematic manner and put it into engineering systems, together with other information like mathematical model and sensory information.

The action modelled in Simulink power systems is base on fuzzy logic applications. The structure of fuzzy logic controller circuit as shown in fig9. Control action formation includes four stages.

A)Getting the input values of parameter deviation

B)Fuzzification (transforming into fuzzy form) of the inputs.

C)Determination of fuzzy control action

D)Defuzzification (transforming the linguistic values into quantitative form) of the control action.

Fig.9 shows the internal of the control circuit. Control scheme consists of fuzzy controller, a limiter and a 3-phase sine wave generator for the generation of reference currents and switching pulses.

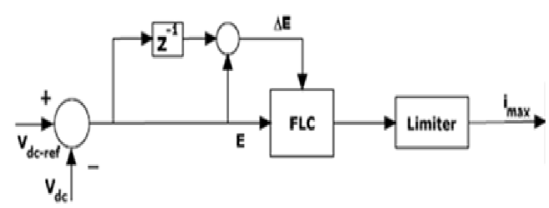

Fig. 9. Fuzzy controller circuit.

The actual capacitor voltage is compared with reference value. The error signal is then processed through a fuzzy controller, which contributes to the zero steady in tracking the reference current signal. Membership function values are assigned to the linguistic variables using seven fuzzy subset called negative big (nb) , negative medium (nm) , negative small (ns) , zero (z) , positive Small (ps) , positive medium (pm) , positive big (pb).Fuzzy associative memory for the proposed system is given in Table-1. Variable e and Δe are selected as the input variables for FLC where e is the error between the reference signal and actual signal of the system; Δe is the change in error in the sampling interval. Then the output variable of fuzzy logic controller is presented by the current by $I_{max.}$

Table 1.Rule Table of the Fuzzy Controller

ε /Δε	NB	NM	NS	ZE	PS	PM	PB
NB	**NB**	**NB**	**NB**	**NB**	**NM**	**NS**	**ZE**
NM	**NB**	**NB**	**NM**	**NM**	**NS**	**ZE**	**PS**
NS	**NB**	**NM**	**NS**	**NS**	**ZE**	**PS**	**PM**
ZE	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
PS	**NM**	**NS**	**ZE**	**PS**	**PS**	**PM**	**PB**
PM	**NS**	**ZE**	**PS**	**PM**	**PM**	**PB**	**PB**
PB	**ZE**	**PS**	**PM**	**PB**	**PB**	**PB**	**PB**

4. Simulation model

Series Active Filter:

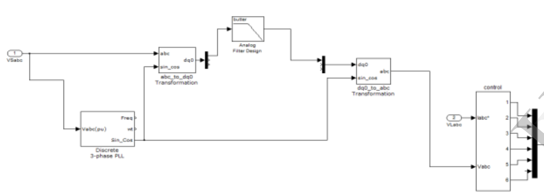

Fig 10: Series Active Filter

An algorithm to control the series filter as shown in fig.10, the series filter is controlled such that it injects voltages which cancel out the distortions and/or unbalance present in the supply voltages thus making the voltages at the PCC perfectly balanced and sinusoidal with the desired amplitude. Since the supply voltage is unbalanced and or distorted, a phase locked loop (PLL) is used to achieve synchronization with the supply. Three phase distorted/unbalanced supply voltages are sensed and given to the PLL which generates two quadrature unit vectors. The sensed supply voltage is given to d-q transformation block and the output of d-q transformation is given to a low pass filter and inverse d-q transformation is done. The transformed supply voltages are compared with the reference load voltages and given to a hysteresis controller. The output of the hysteresis controller is switched signals to the six switches of the VSI of the series AF. The hysteresis controller generates the switching signals such that the voltage at the PCC becomes the desired sinusoidal reference voltage. Therefore, the injected voltage across the series transformer through the ripple filter cancels out the harmonics and unbalance present in the supply voltage.

Shunt Active Filter:

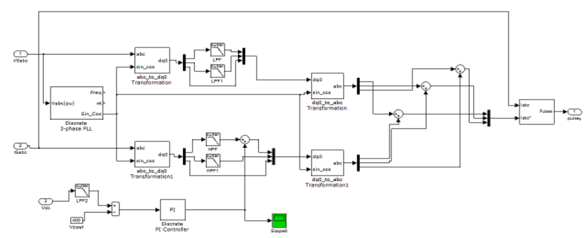

Fig 11: Shunt Active Filter

An algorithm to control shunt filter as shown in Fig.11.If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics of load current. The actual dc-link voltage is sensed and passed through a first-order low pass filter (LPF) to eliminate the presence of switching ripples on the dc-link voltage. The difference of this filtered dc-link voltage and reference dc-link voltage is given to a discrete-PI controller to maintain a constant dc-link voltage under varying generation and load conditions. The three phase source voltages and currents are given to the PLL to achieve synchronization with supply. The voltages and currents are transformed from abc to dq0 to generate the reference currents. The reference grid currents are compared with actual grid currents to compute the current errors. These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses (P1 to P6) for the gate drives of the shunt inverter.

5. Simulation Results

A simulation study is carried out by using MATLAB/Simulink in order to verify the proposed control approach. In this paper 3 phase 3 wire UPQC system with an improved Control Method under Distorted and Unbalanced Load Conditions and DC link voltage is controlled by PI and Fuzzy controller results are presented**.**

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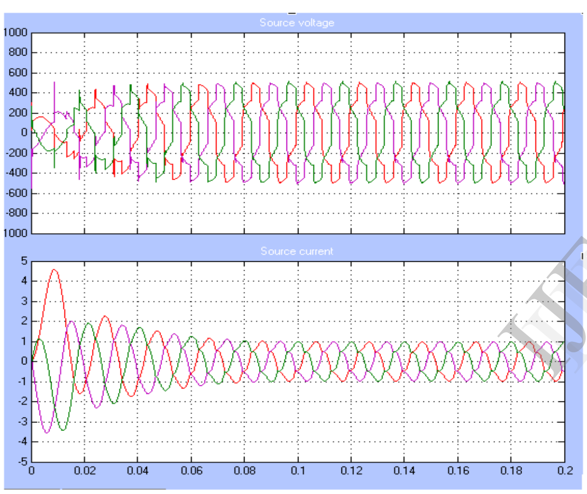
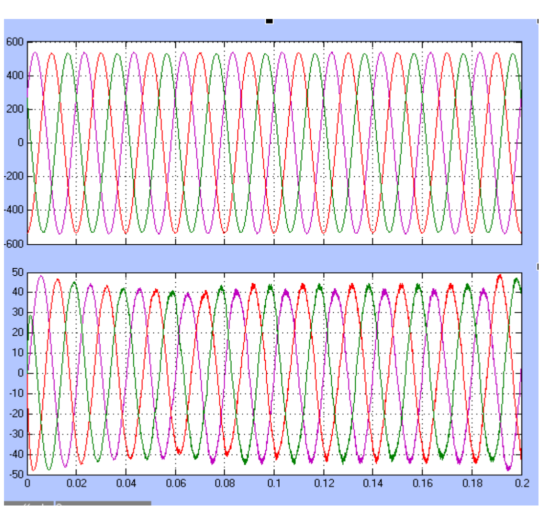
Table 2.System Parameters

3-phase supply (rms)	380v
3-phase Non-linear load	R=100Ω,L=100μH
Dclink Capacitance &voltage	$C_{dc} = 12000\mu F, V_{dc} = 400V$



(a)



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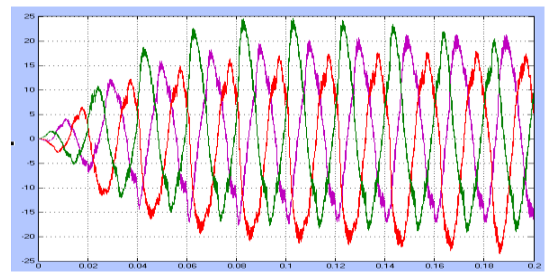
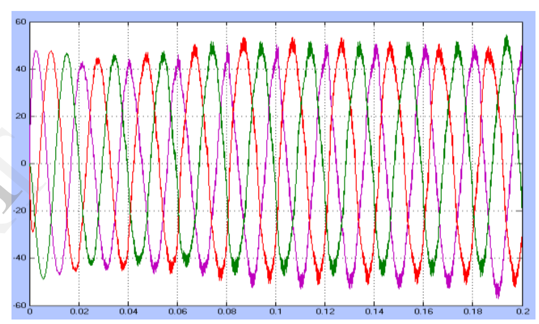


(c)



(d)

Fig 12: Simulation results a) Three phase source voltage and current without UPQC system b) Supply voltage and current after adding UPQC system c) Three phase compensating current d) Three phase load current

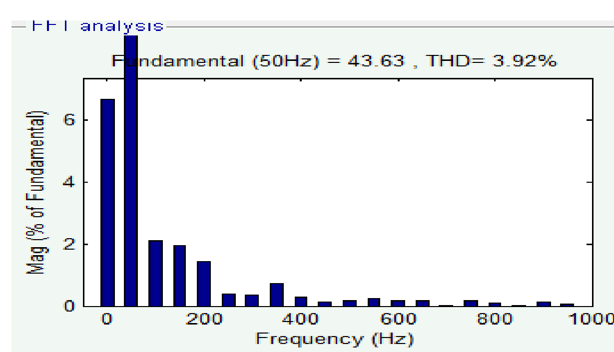


Fig 13:THD value of source current by using PI controller in shunt APF for one cycles is 3.92% .

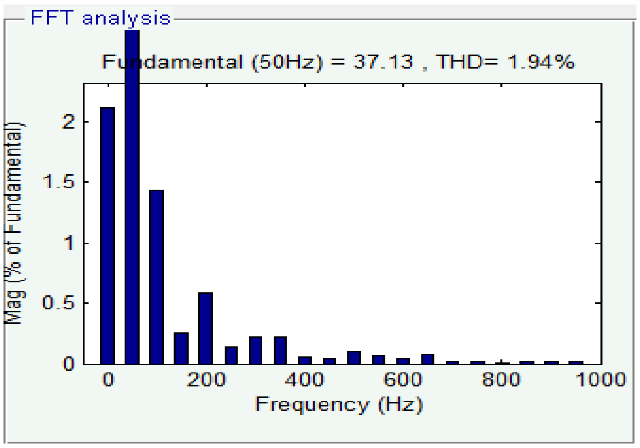


Fig 14: THD value of source current by using fuzzy controller in shunt APF for one cycles is 1.94% .

From Fig13,Fig14. We can see that THD value of source current with PI Controller and fuzzy controller is 3.92% and 1.94% here we can say that by using Fuzzy we can reduce 1.98% .

6. Conclusion

The power quality problems in distribution systems are not new but customer awareness of these problems increased recently. It is very difficult to maintain electric power quality at acceptable limits. One modern and very promising solution that deals with both load current and supply voltage imperfections is the Unified Power Quality condition (UPQC). This paper has presented a review of UPQC about its physical structure, converter topology, supply system, system configuration, and control strategy and system description. And it also proposes the implementation of a three-phase active power filter with two controllers(PI and Fuzzy)even though both the controllers capable of compensating current harmonics in 3-phase 3-wire systems,it can be seen that fuzzy logic controller has fast response and low THD values of current as the results are shown above using MATLAB simulink.

Acknowledgment

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References

[1] C.Sarkaran,Power Quality,Boca Raton: CRC Press, 2002,p.202.

[2] H. Fujita, and H. Akagi, "The unified power quality conditioner: The integration of series and shunt-active filters, " IEEE Trans. Power Electron., vol. 13, no. 2, pp. 315-322, Mar. 1998.

[3] Vinod Khadkikar, "Enhancing Electric Power Quality Using UPQC: A Comprehensive Overview", IEEE TRANSACTIONS ON POWER ELECTRONICS, Vol. 27, No. 5, MAY 2012.

[4] Control strategies for series and shunt active filters Mauricio Ardes,Luis F.C Monteiro,Jamie M.Miguel IEEE Bolgna Power Tech Conference,June 23th-26th,Bologna,Italy.

[5] RVD Rama Rao and Dr.subhransu.sekhar.Dash "power quality enhancement by unified power quality conditioner using ANN with hysteresis control."International journal of computer applications (0975 - 8887)volume6No.1,September 2010.

[6] MATLab inc,MATLAB::FuzzyLogic toolbox

[7] Neural NetworksFuzzy logic:Synthesis and Applications by Rajashekharan and Rai-PHI Publication.

[8] Suresh Mikkili and Anup Kumar Panda "PI and Fuzzy logic controller based 3-phase 4-wire Shunt Active Filters for the Mitigation of current Harmonics with the Id-Iq Control Strategy", journal of Power electronics,vol. 11,No. 6,November 2011