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Fuzzy Logic Based Upqc Controller For Compensating Power Quality Problems

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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 determination of voltage references for series active power filter is based on a robust three phase digital phase locked loop (PLL) system using fuzzy regulator. Control strategies related to fuzzy hysteresis band voltage and current control methods, where the band is modulated with the system parameters to maintain the modulation frequency nearly constant are developed. The FLC-based compensation scheme eliminates voltage and current magnitude of harmonics with good dynamic response. The effectiveness and flexibility of the proposed system confirmed by Matlab/ Simulink simulations.

Key words: Unified Power Quality Conditioner, Power Quality, Phase locked loop, Fuzzy Logic Controller, Harmonics

INTRODUCTION

Power quality problem has become a significant issue in recent years due to the high number of power electronic devices that behave like nonlinear loads and generate several perturbations in the electric grid (McGranaghan, et al., 1996; Short, T.A., 2004; Heine, P., 2003; IEEE, 1993). 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. Unified Power Quality Conditioner systems were widely studied by many researchers as an eventual method to improve the PQ in electrical distribution systems (Akagi, H. and H. Fujita, 1995; Fujita, H. and H. Akagi, 1998; Akagi, H., et al., 2007; Graovac, D., V. Katic, 2007; Han, B., et al., 2006; Esfandiari, A., et al., 2008). The aim of a UPQC is to eliminate the disturbances that affect the performance of the critical load in power systems. The UPQC, therefore, is expected to be one of the most powerful solutions to large-capacity loads sensitive to supply-voltage-imbalance distortions. The UPQC, which has two inverters that share one dc link, can compensate the voltage sag and swell and the harmonic current and voltage, and it can control the power flow and voltage stability. Moreover, the UPQC with the combination of a series active power filter (APF) and a shunt APF can also compensate the voltage interruption if it has some energy storage or battery in the dc link (Akagi, H., et al., 2007). A typical configuration of UPQC is shown in fig. 1. This paper is focused on voltage sag and along with current and voltage harmonics compensation based on fuzzy hysteresis band control. The UPQC performances will depend on the design of power semiconductor devices, on the modulation technique used to control the switches, on the design of coupling elements, on the method used to determine active filters current and voltage references and on the dynamics and robustness of current and voltage control loops.

For the SAF, the standard instantaneous symmetrical component theory is used to determine reference source current (Ghosh, A. and A. Joshi, 2002). Among various PWM techniques, hysteresis fixed band current control is popularly used because of its simplicity of implementation. As a result, the switching losses are increased and current sources contain excess ripples (Rahman, et al., 1997). The current controller performances can be improved by using adaptive control system theory (Mekri, F., et al., 2006; Jiang Zeng a et al., 2004). An adaptive hysteresis band current control PWM technique can be programmed as a function of supply and APF parameters in order to maintain a fixed modulation frequency. Unfortunately, adaptive control is very sensitive to parameters system and its global stability is hard to be proved. A new technique, based on the same concept, but where the hysteresis band is implemented with fuzzy logic is proposed to optimize the PWM performances.

For the SAF, a robust PLL system is used for supply voltage disturbances identification. The PLL is developed to achieve good results under unbalanced, interruption or distorted voltage conditions based on a fuzzy logic regulator. Appropriate fuzzy hysteresis band voltage controller is also synthesized for SAF output

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voltage control. Simulation results will be shown and discussed in the last section to verify the performances of the proposed UPQC in different conditions such as voltage and current harmonics.

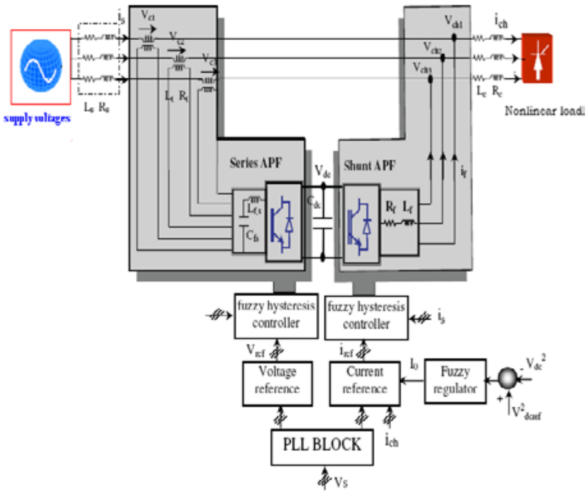


Fig. 1: Unified Power Quality Conditioner basic principle

II. Equivalent Circuit of Unified Power Quality Conditioner:

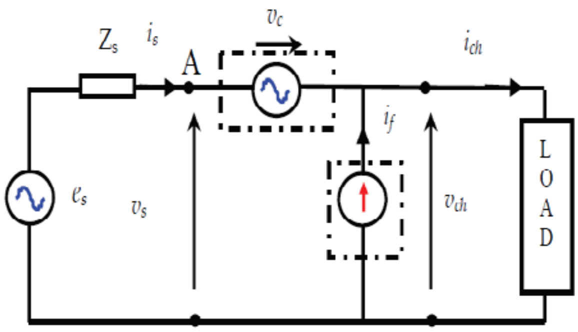


Fig. 2: Equivalent Circuit of a UPQC

A UPQC control system is used for simultaneous voltage regulation and current compensation in the presence of unbalance and harmonics in both load currents and source voltages. The UPQC is controlled in such a way that the voltage at load bus is always sinusoidal and at desired magnitude. 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 (Singh, B., et al., 1999). In addition, it controls dc link current to a desired value. The single phase equivalent circuit for a UPQC is shown in fig. 2. The source voltage; terminal voltage at PCC and load voltage are e_s,v_s and v_{ch} respectively. The source and load currents are i_s and I_{ch}respectively. The voltage injected by SAF is v_c *and* i_f is the current injected by PAF.

III. Control Of Shunt Active Filter:

III.1 Generation of Reference current:

The objective is to get sinusoidal line currents in phase with the supply voltages at the common coupling point. The well known instantaneous symmetrical component theory is used to determine the current references .The distorted supply voltages conditions may result in partial compensated source current. To overcome this problem, a robust PLL system is first used to extract the fundamental positive sequence voltage components. The reference current for STATCOM is calculated by instantaneous symmetrical component theory. The objective of compensation is to provide balanced supply current such that its zero sequence component is zero. We therefore have

$$i_{sa}+i_{sb}+i_{sc}=0 \tag{1}$$

$$v_{sa1}=\frac{1}{\sqrt{3}}\left\{v_{sa}+a\,v_{sb}+a^2 v_{sc}\right\} \tag{2}$$

The angle of the vector is then given by

$$\phi=\angle(v_{sa1})=\tan^{-1}\left\{\frac{\frac{\sqrt{3}}{2}v_{sb}-\frac{\sqrt{3}}{2}v_{sc}}{v_{sa}-\frac{1}{2}v_{sb}-\frac{1}{2}v_{sc}}\right\}=\tan^{-1}\left\{\frac{\frac{\sqrt{3}}{2}(v_{sb}-v_{sc})}{\frac{3}{2}\;v_{sa}}\right\} \tag{3}$$

If we now assume that the phase of the vector i_{sa1} lags that of v_{sa1} by an angle Φ, we get

$$\angle\left\{v_{sa}+a\,v_{sb}+a^2 v_{sc}\right\}=\angle\left\{i_{sa}+a\,i_{sb}+a^2 i_{sc}\right\}+\Phi \tag{4}$$

Substituting the values of a and a^{2,}

$$\angle\left\{(v_{sa}-\frac{1}{2}v_{sb}-\frac{1}{2}v_{sc})+j\frac{\sqrt{3}}{2}(v_{sb}-v_{sc})\right\}=\angle\left\{(i_{sa}-\frac{1}{2}i_{sb}-\frac{1}{2}i_{sc})+j\frac{\sqrt{3}}{2}(i_{sb}-i_{sc})\right\}+\Phi \tag{5}$$

Equating the angles, we can write from the above equation

$$\tan^{-1}\left(k1/k2\right)=\tan^{-1}\left(k3/k4\right)+\Phi \tag{6}$$

where

$$k1=\frac{\sqrt{3}}{2}(v_{sa}-v_{sb}) \quad , \quad k2=(v_{sa}-\frac{1}{2}v_{sb}-\frac{1}{2}v_{sc})$$

$$k3=\frac{\sqrt{3}}{2}(i_{sa}-i_{sb}) \quad , \quad k4=(i_{sa}-\frac{1}{2}i_{sb}-\frac{1}{2}i_{sc})$$

$$\frac{k1}{k2}=\tan\left\{\tan^{-1}\left(\frac{k3}{k4}\right)+\Phi\right\}=\frac{(k3/k4)+\tan\Phi}{1-(k3/k4)\tan\phi}$$

Solving the above equation we get

$$\begin{aligned}&(v_{sb}-v_{sc}-3\beta\,v_{sa})i_{sa}\\&+(v_{sc}-v_{sa}-3\beta\,v_{sb})i_{sb}+(v_{sa}-v_{sb}-3\beta\,v_{sc})i_{sc}=0\end{aligned} \tag{7}$$

$$\beta=\tan\phi/\sqrt{3} \tag{8}$$

When the power factor angle is assumed to be zero, the instantaneous reactive power supplied by the source is zero. On the other hand, when this angle is non-zero, the source supplies a reactive power that is equal to β times the instantaneous power.The instantaneous power in a balanced three-phase circuit is constant while for an unbalanced circuit it has a double frequency component in addition to a dc value. In addition, the presence of harmonics adds to the oscillating component of the instantaneous power .The objective of the compensator is to supply the oscillating component such that the source supplies the average value of the load power. Therefore

$$v_{sa}i_{sa}+v_{sb}i_{sb}+v_{sc}i_{sc}=p_{lav} \tag{9}$$

where p_{lav} is the power drawn by the load. Since the harmonic component in the load does not require any real power, the source only supplies the real power required by the load. Therefore,

$$\begin{bmatrix}1 & 1 & 1\\ v_{sb}-v_{sc}-3\beta v_{sa} & v_{sc}-v_{sa}-3\beta v_{sb} & v_{sa}-v_{sb}-3\beta v_{sc}\\ v_{sa} & v_{sb} & v_{sc}\end{bmatrix}\begin{bmatrix}i_{sa}\\ i_{sb}\\ i_{sc}\end{bmatrix}=\begin{bmatrix}0\\0\\p_{lav}\end{bmatrix} \tag{10}$$

Assuming that the current are tracked without error, the KCL at PCC can be written in terms of the reference currents as

$$\mathbf{i}^*_{\mathbf{fk}} = \mathbf{i}_{\mathbf{lk}} - \mathbf{i}_{\mathbf{sk}} \tag{11}$$

where k=a, b, c.

Reference compensator currents are

$$\mathbf{i}^*_{\mathbf{fa}} = \mathbf{i}_{\mathbf{la}} - \frac{\mathbf{v}_{\mathbf{sa}} + (\mathbf{v}_{\mathbf{sb}} - \mathbf{v}_{\mathbf{sc}})\beta}{\mathbf{v}^2_{\mathbf{sa}} + \mathbf{v}^2_{\mathbf{sb}} + \mathbf{v}^2_{\mathbf{sc}}}\mathbf{p}_{\mathbf{lav}}$$
$$\mathbf{i}^*_{\mathbf{fb}} = \mathbf{i}_{\mathbf{lb}} - \frac{\mathbf{v}_{\mathbf{sb}} + (\mathbf{v}_{\mathbf{sc}} - \mathbf{v}_{\mathbf{sa}})\beta}{\mathbf{v}^2_{\mathbf{sa}} + \mathbf{v}^2_{\mathbf{sb}} + \mathbf{v}^2_{\mathbf{sc}}}\mathbf{p}_{\mathbf{lav}}$$
$$\mathbf{i}^*_{\mathbf{fc}} = \mathbf{i}_{\mathbf{lc}} - \frac{\mathbf{v}_{\mathbf{sc}} + (\mathbf{v}_{\mathbf{sa}} - \mathbf{v}_{\mathbf{sb}})\beta}{\mathbf{v}^2_{\mathbf{sa}} + \mathbf{v}^2_{\mathbf{sb}} + \mathbf{v}^2_{\mathbf{sc}}}\mathbf{p}_{\mathbf{lav}} \tag{12}$$

III.2. DC voltage control:

Block diagram of shunt APF control is shown in fig 3.In the UPQC the management of DC bus concerns the role of the PAF. This one determines the active power necessary to keep constant the DC voltage in steady state or transient conditions There are three principal factors that affect the voltage fluctuations of the DC capacitor. The first is the alternating power of the load to be compensated, the second is the active power imbalance during transients and the third is the active power absorbed by the SAF part for compensating network voltage sag. If a power imbalance occurs; because of load changing or voltage dips; the PAF should consume or supply real power. This power is given by

$$P_f = P_{dc} - P_a = 3V_s(\,I_{ch}\cos\varphi_1 - I_s) \tag{13}$$

Where I_1 is fundamental current of the load and φ_1 it phase,P_{dc} is the DC power consumed by the non-linear load, P_a is the active power provided by the supply.

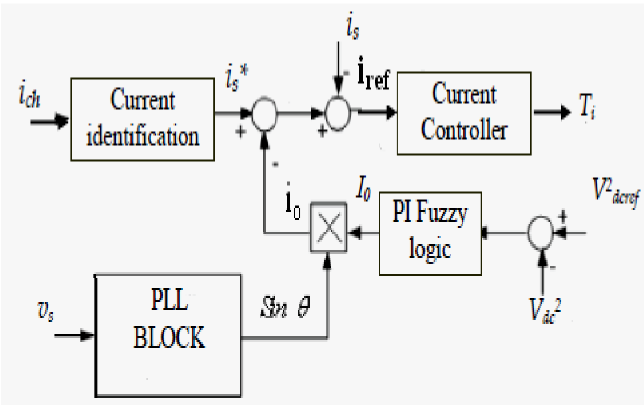


Fig. 3: Block diagram of shunt APF control

III.3 Fuzzy Adaptive Hysteresis Current Controller:

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FLC (Mokhtatpour, A. and H. Shayanfar, 2011). The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as; i. seven fuzzy 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 'height' method. The knowledge bases are designed in order to obtain a good dynamic response under uncertainty in process parameters and external disturbances. In our application, the fuzzy controller is based on processing the voltage error and its derivation $\bar{e}$. The input variable 'e' is

$$e = v_{dc}^{*2} - v_{dc} \tag{14}$$

Fig.4 shows the membership functions of the input and the output linguistic variables.In the fuzzification stage numerical values of the variables are converted into linguistic variables. Seven linguistic variables namely NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) are assigned for each of the input variables and output variable. Normalized values are used for fuzzy implementation. As there are seven variables for inputs and output there are 7 × 7 = 49 input output possibilities as tabulated in Table. 1. A membership function value between zero and one will be assigned to each of the numerical values in the membership function graph. In this paper, we applied max-min inference method to get implied fuzzy set of the turning rules.

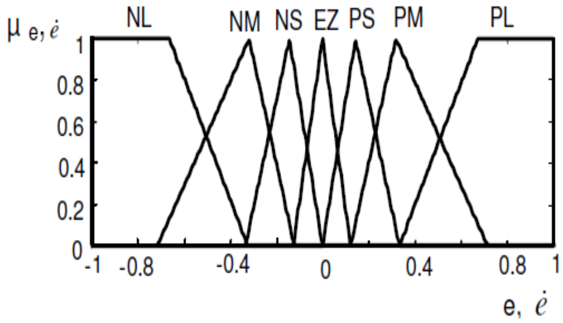


Fig. 4: Membership functions for input variables (e, *e*&) and output variables.

Table 1: Rules of inference for the DC voltage

$\bar{e}$ /e	NL	NM	NS	EZ	PM	PS	PL
NL	NL	NL	NL	NL	NM	NS	EZ
NM	NL	NL	NL	NM	NS	EZ	PS
NS	NL	NL	NM	NS	EZ	PS	PM
EZ	NL	NM	NS	EZ	PS	PM	PL
PM	NM	NS	EZ	PS	PM	PL	PL
PS	NS	EZ	PS	PM	PL	PL	PL
PL	EZ	PS	PM	PL	PL	PL	PL

The core of active filter is the control section that must be able to derive the reference current waveform matching the harmonic content of the line current and to drive the inverter producing a filtering current faithfully tracking the reference one. The objective is to get sinusoidal line currents in phase with the supply voltages at the common coupling point. Fixed hysteresis band method is very simple and easy to implement, but has several known disadvantages such as uncontrollable high switching frequency and induced switching losses. These problems result in high current ripples, acoustic noise and difficulty in designing input filter. To improve this control, an adaptive fuzzy hysteresis band current control technique can be programmed as a function of the active filter and supply parameters to minimize the influence of current distortions on modulated waveform (Ying-Yu Tzou, Shiu-Yung Lin, 1998). The band (HB) can be modulated at different points of fundamental frequency of the cycle to control the PWM switching pattern of the inverter.

The hysteresis band is given by:

$$HB = \left\{ \frac{0.125V_{dc}}{f_s L_f} \left[1 - \frac{4{L_f}^2}{{V_{dc}}^2} \left(\frac{V_s}{L_f} + \frac{di^*}{dt} \right)^2 \right] \right\} \tag{15}$$

Eqn.15 shows the hysteresis bandwidth as a function of modulation frequency, supply voltage, dc capacitor voltage and slope of the reference current wave. Hysteresis band can be modulated as a function of V_s and $\frac{di^*}{dt}$. Hence, these variables are taken as input to the fuzzy controller, and the hysteresis band width (HB) is the output. In a hysteresis controller the reference compensation current is compared with the actual current that is being injected by the compensation circuit, (Mekri, F., et al., 2008). A positive pulse is produced if the actual current tends to decrease below the lower hysteresis limit, while a negative pulse is produced if the current exceeds the upper hysteresis limit (Liu, R., et al., 2009). Thus in a hysteresis current controller the actual compensation current is forced to stay within a particular hysteresis band. Each input variables is transformed into linguistic size with five fuzzy subsets, PL, PM, PS, EZ, NL and NM. For the output variable HB, PVS is positive very small and PVL is positive very large. The resulting rule is presented in Table II.

Table II: Rules of inference for Fuzzy hysteresis current control

d_{is1}*/dt $v_s(t)$	NL	NM	EZ	PM	PL
NL	PS	PS	PM	PS	PS
NM	NL	PM	PL	PM	PS
EZ	PVS	PM	PVL	PM	PVS
PM	NL	PM	PL	PM	PS
PL	PS	PS	PM	PS	PS

IV.Control Of Series Active Filter:

IV.1 Generation of Reference voltage:

A DVR based on a pulse-width modulated (PWM) VSI, which is capable of generating or absorbing real and reactive power independently at its ac output terminals is used as the series compensator. The series compensator injects three single-phase ac voltages in series and in synchronism with the upstream voltages in the distribution system. The power circuit could be divided into two main parts: three-phase VSI, three single-phase injection transformers. The three single-phase transformers are connected to the distribution system with a star/open winding. The star/open winding allows the injection of positive, negative and zero sequence voltages. The windings on the inverter side are connected in delta through inductors to provide high voltage (Vinod Khadkikar, Ambrish Chandra, 2011). The reference voltage for DVR is calculated by instantaneous symmetrical component theory. The source is connected to the DVR by a feeder with an impedance of R+jX. Using KVL at PCC we get,

$$v_t + v_f = v_l \qquad (16)$$

The main aim of the DVR is to make the load voltage a strictly positive sequence. Furthermore, the DVR must not supply or absorb any real power. To force v_l to be positive sequence v_f must cancel the zero-and negative-sequence components of v_t. Here the DVR must operate in zero power mode,

$$p_{lav} = p_{tav} = v_{ta}i_{sa} + v_{tb}i_{sb} + v_{tc}i_{sc} \qquad (17)$$

where p_{tav} is the average value of the instantaneous power entering the terminal and p_{lav} is the instantaneous power supplied to the load.Let us denote the phasor load voltage as

$$V_l = |V_1| \angle \vartheta \qquad (18)$$

Since the load voltage is strictly positive sequence, the average power to the load is also positive sequence (Vinod Khadkikar, 2012). Therefore,

$$P_{lav} = |V_1||I_{l1}|\cos(\vartheta - \phi) \qquad (19)$$

Therefore, Reference compensator voltagess are,

$$v_{fo}^* = -v_{to}\,,\; v_{f1}^* = |v_l|_{\angle\theta} - v_{t1},\; v_{f2}^* = -v_{t2} \qquad (20)$$

An inverse symmetrical component transformation of above equation produces the reference phasor voltages of the DVR.The proposed method is based on a robust PLL system and is able to detect quickly any voltage drop due to dips or flickers besides voltage harmonics in the network.The PLL block allows to detect the amplitude and phase of fundamental positive sequence components of the utility voltages.The detailed block diagram of the PLL, which can be completely implemented in software,is presented in fig. 5. The PLL block allows to control of an estimated phase angle with respect to the angle θ_s of mains voltage.

The functional diagram of the PLL based on a fuzzy PI regulator is shown in fig.6. The knowledge obtained on the behavior of the system is put in the form of rules, which are summarized in Table 1 of inference.

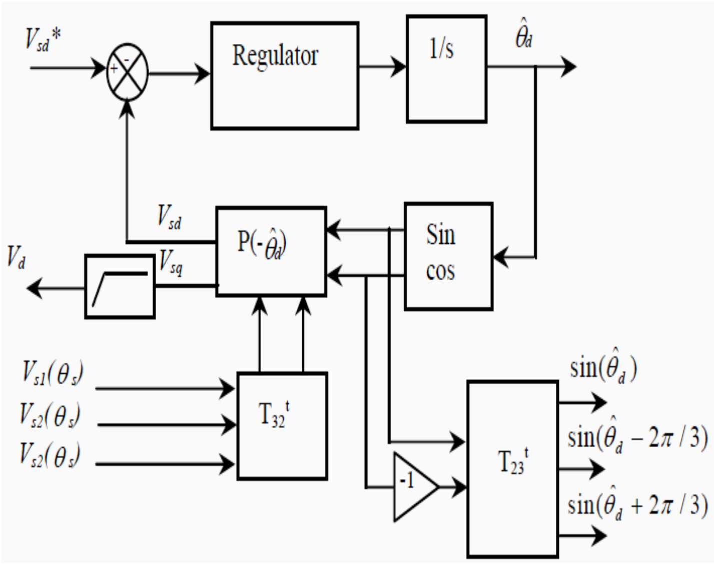


Fig. 5: Detailed block Diagram of the PLL

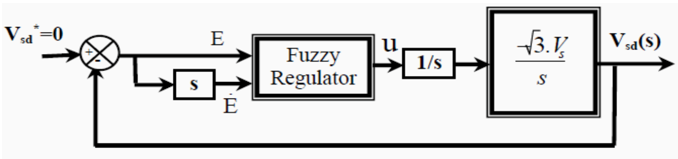


Fig. 6: Functional Diagram of the PLL with the fuzzy regulator

A fuzzy hysteresis band control is adopted allowing to operate at nearly fixed frequency. The adaptive hysteresis band is given by:

$$HB = \frac{V_{dc}}{6 f_c R_{fs} C_{fs}} \left(1 - \frac{9 (R_{fs} C_{fs})^2}{4 V_{dc}^2} \left(\frac{V_{sl}(t)}{R_{fs} C_{fs}} + \frac{d V_{ref}(t)}{dt}\right)^2\right) \tag{21}$$

This equation shows that the hysteresis band can vary while keeping the switching frequency nearly constant. In order to establish a fuzzy logic controller, the input and the output variables are again treated. The voltage reference slope and it derivation are selected as input variables and HB as output variable. PWM technique is used to generate switching patterns for the VSI.The partition of fuzzy subsets and the shape of membership function adapt the shape up to appropriate system. The value of input error *E(k)* and change in error *CE(k)* are normalized by an input scaling factor. In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular input there is only one dominant fuzzy subset. Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. To compute the output of the FLC, „height‟ method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. The set of FC rules are derived from equation (22).

$$U=-[\propto E+(1-\propto)*C] \tag{22}$$

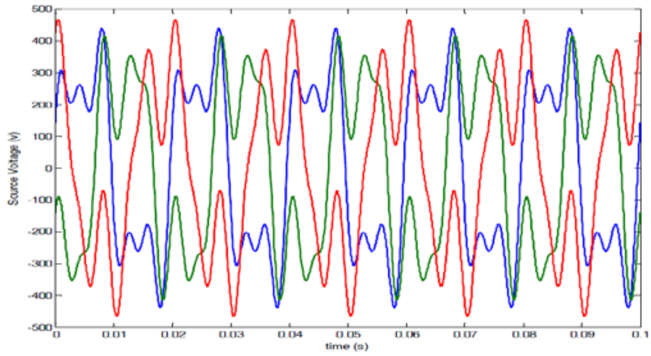
Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. On the other hand, small value of the error E indicates that the system is near to balanced state. During the process, it is assumed that neither the UPQC absorbs active power nor it supplies active power during normal conditions. So the active power flowing through the UPQC is assumed to be constant. The set of FC rules is made using Fig.6 is given in Table 2.

V. Simulation Results:

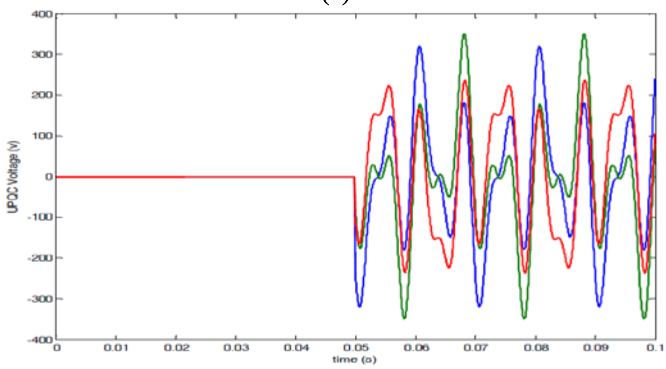
This section presents the details of the simulation carried out to demonstrate the effectiveness of the proposed control strategy for the active filter for harmonic current filtering, reactive power compensation, load current balancing and neutral current elimination,. All the compensators are implemented using equivalent discrete blocks. To observe the performance of shunt filter for voltage correction the shunt is switched on first, and then the series filter is switched on. The parameters of simulation are:V_{dc}=1250V,Vs=220V,L_{fs}=5*10^{-4} $_{H,}$ C_{fs}=69 *10^{-4} F,f_c=8.5kHz,R_s=0.6 mW, L_s=10 μH and L_f= 140μH . The non-linear load is composed by a diode rectifier feeding an R-L load (R_d=0.7W,L_d= 5mH).

V.1.Compensation of Load voltage:

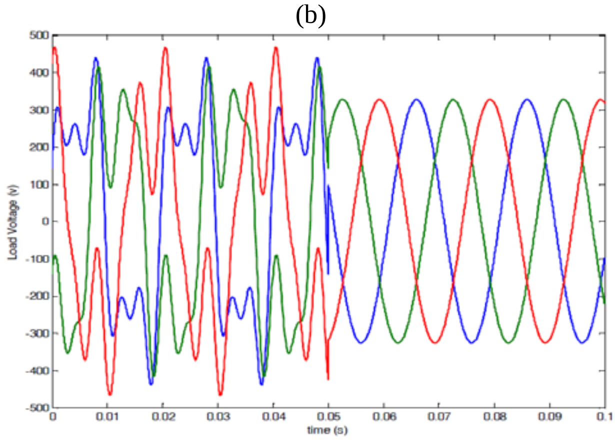
Fig7,shows behaviour of the PLL block under excessive distorted and unbalanced supply voltages, compensating voltage of UPQC and well-corrected load voltage, respectively. The series APF starts compensating for the voltage harmonics immediately by injecting out of the phase harmonic voltage, making the load voltage distortion-free. The voltage injected by the series APF is shown in Fig.7(b). Here, the load voltage THD is improved from 16..27% to 0.53%.These results of simulations show us that the application of fuzzy logic in the control loops makes it possible to fulfil the desired requirements concerning the locking of PLL, even under the most unfavourable conditions. DC link voltage of UPQC during occurrence of unbalanced voltage is shown in fig 8.



(a)



(b)



(c)

Fig. 7: Harmonic correction of voltages; a: Source Voltage; b: Reference Voltage; c: Corrected Voltage at load side

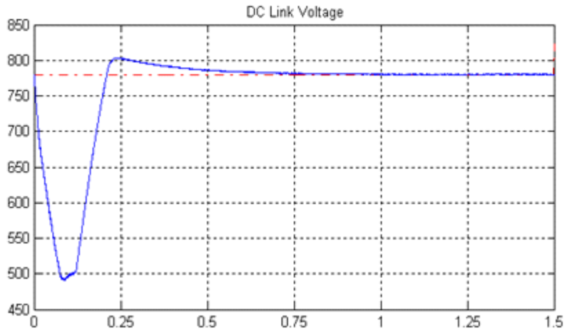


Fig. 8: DC link voltage of UPQC during occurrence of unbalanced voltage

V.2.Compensation Of Voltage Interruption:

Fig. 9 shows the simulation results when the source has a voltage interruption for 0.06 s from 0.06 to 0.12s. Fig.9(a) and (b) shows the source voltage and the load voltage respectively. The load voltage maintains a constant value by the support of the shunt inverter voltage. Fig.10 shows the DC voltage variation of the DC bus. During the voltage interruption, the shunt inverter only provides power to the load. The voltage of DC bus maintains a constant value by the support of FLC during the voltage interruption. Thus, it shows the stability and the reliability of the proposed system. Fig. 10: DC link voltage oscillation under voltage interruption.

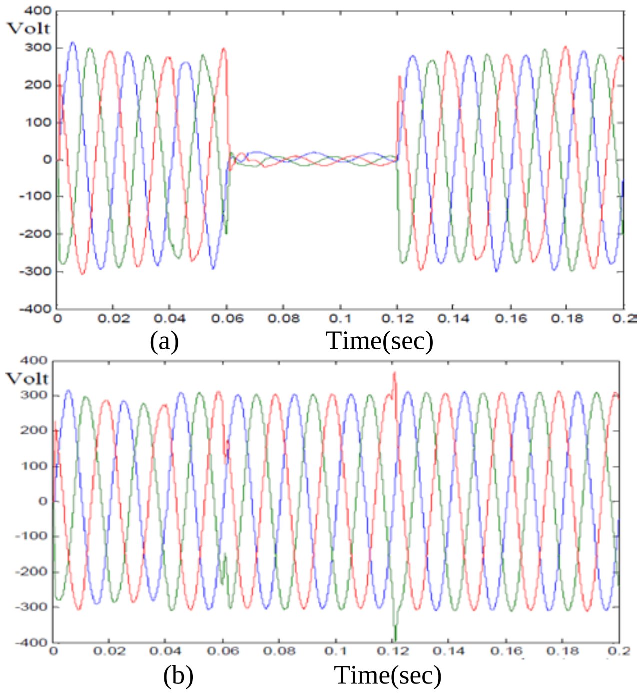


Fig. 9: Voltage compensation under interruption. (a). Source Voltage (b) Compensated voltage at PCC

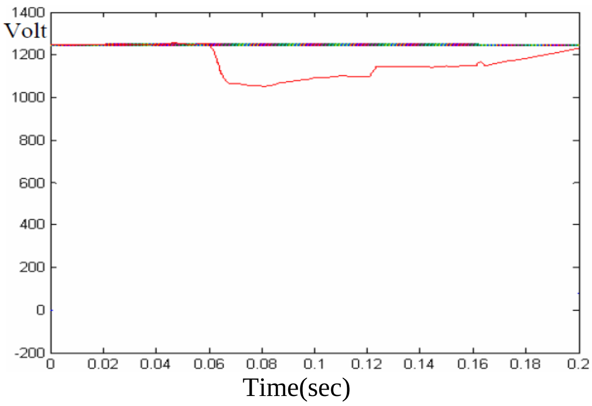
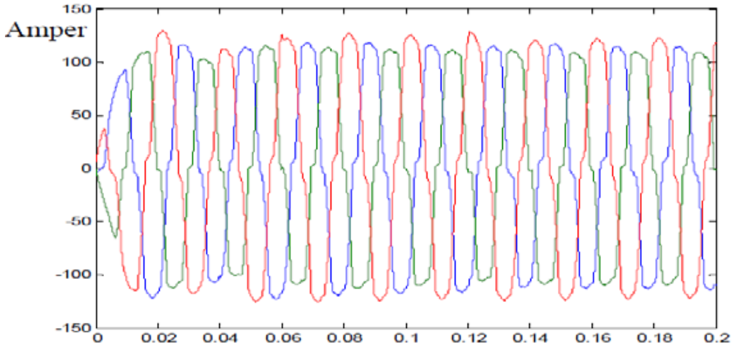


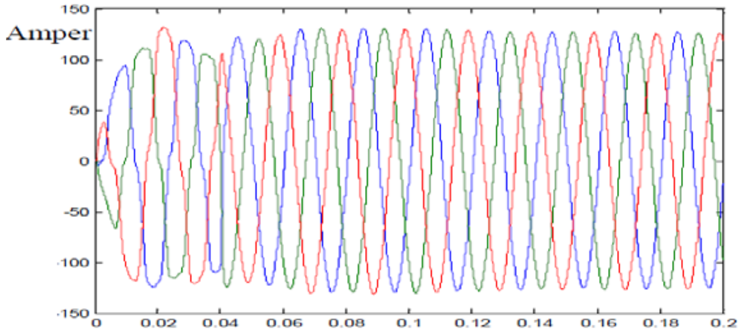
Fig. 10: DC link voltage oscillation under voltage interruption

V.3. Compensation Of Current Harmonics And Unbalanced Currents:

Fig.11 shows the effectiveness of the proposed system for compensation of current harmonics and unbalanced currents. It shows the simulation results when the shunt inverter of UPQC operates as an active power filter. Fig.11(a)–(b) shows the current waveform of the load and the source, in which the load current can be compensated by the shunt-inverter current to make the source current sinusoidal. The performance of the proposed control algorithm of the active power filter is found to be excellent and the source current is practically sinusoidal. The THD decreases from 29.5% before filtering to 2% for fuzzy hysteresis band control after filtering.



(a) Time(sec)

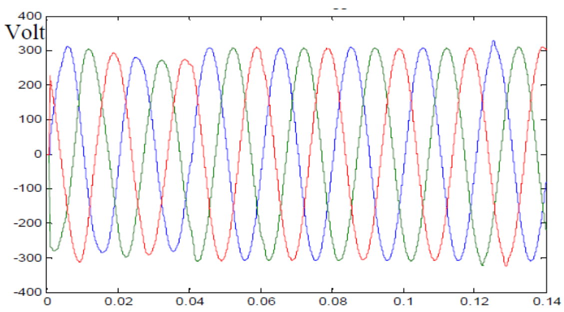


(b) Time(sec)

Fig. 11: Unbalanced current and current harmonic compensation.
a) load currents b) compensated currents

V.4. Compensation Of Voltage Sag:

Fig. 12 shows the simulation results when the source has almost 30% of three-phase voltage sag. Fig.12(a) and (b) shows the source voltage and the load voltage. The load voltage maintains a constant value as expected. During the sag interval, the reverse-flow source power is reduced and the series inverter covers this reduced amount to maintain the load power constant. Results show that UPQC is maintaining the load voltage sinusoidal and at desired constant level even during the sag. While SAF is providing the required real power to the load, the PAF is maintaining the DC link voltage at constant level and the source delivered more current.

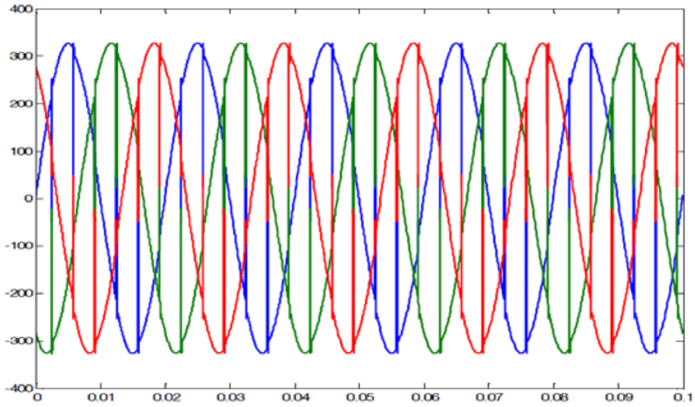


(a) Time(sec)

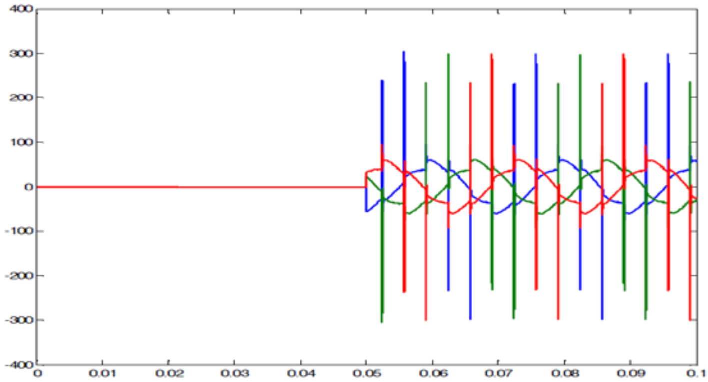
Fig. 12: Voltage sag compensation. a)source voltages b) load voltages

V.5 Compensation of Voltage Sag:

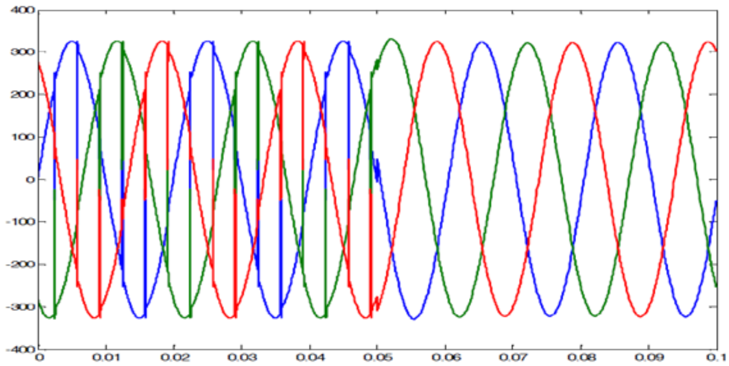
Fig 13:a-c show the network voltages, UPQC and corrected voltage of load, respectively. As it is seen in Figure 13-c the load voltage is completely corrected after t=0.05 s which UPQC is activated.



(a) Time(sec)



(b) Time(sec)



(c) Time(sec)

Fig. 13: Voltage correction of notch generator load A: Source Voltage B: UPQC Voltage C: Corrected Voltage at load side

Conclusion:

A control design for the UPQC, which is adaptive to the variations of the supply and load operating conditions of a power distribution system, has been proposed. The determination of voltage references for series active power filter based on a robust three phase digital locked loop (PLL) using fuzzy logic regulator has been presented. The PLL system has a good reliability, a fast tracking performances and assures a good attenuation of undesirable supply voltage frequencies. It has been shown that, the UPQC can tightly regulate the voltage of the critical load and, at the same time, correct the bus voltage from harmonics and unbalance based on a new hysteresis fuzzy band voltage and current control. 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.

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