POWER QUALITY IMPROVEMENT BY UPQC WITH FUZZY LOGIC CONTROLLER.

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Abstract: *This paper presents analysis of a three-phase four wire Unified Power Quality Conditioner (UPQC) with fully fuzzy logic controller. The UPQC is a custom power device which is integrated by series and shunt active power filters (APF) sharing a common dc bus capacitor. The realization of shunt and series APF is carried out by using a three-phase, three legs Voltage Source Inverter (VSI). In series, shunt active filter, the fundamental voltages, currents are extracted by modified synchronous reference frame technique; Switching pulses for both filters generated by fuzzy logic current controller (FCC).The capacitance voltage is balanced by fuzzy logic controller .performance of the fuzzy logic based control algorithm of shunt active filter with series active filter is evaluated in terms of eliminating the power quality problems in a three-phase, three-wire distribution system with non-linear and unbalanced load conditions. Fuzzy logic control is used for dc capacitance balancing. The control algorithm is made by use of MATLAB / Simulink-based simulations environment and the results are verified by proto type hardware set up*

Key words: *Unified power quality conditioner, Modified Synchronous reference frame technique, Fuzzy logic controller, current and voltage harmonics*

1. Introduction.

In recent years, many researchers give attention to solving power quality problems. These problems are appeared due to usage of reactive loads and non-linear loads. This load create reactive power burden and harmonic problem. This harmonic pollution degrades the quality of power at transmission side as well as distribution side [1]. In literature, many papers have addressed these issues and have proposed the compensating devices for eliminating this problem [1],[2].Usually passive filters are used to eliminate harmonics because of low cost and high efficiency. However, this filters produce resonance with supply frequency therefore active filters are used for suppressing harmonics. The harmonics makes many undesirable effects such as increased heating losses in transformer, poor power factor, malfunction of medical equipments, torque pulsation of motors[3],[4].Power quality problems can be overcome, in real time, through the utilization of "custom power devices"(CPD).The most commonly used CPD is unified power quality controller(UPQC), which is composed by two power converters that are connected in series and in shunt and sharing common dc voltage [5],[6].A shunt converter (also known as the shunt active filter) acts as a harmonic compensator and injects the current in anti–phase with the distortion components present in the line current so that a balanced sinusoidal current flows through the feeder. A series converter is responsible to compensate the major power quality problems related and with the voltage delivered to the load remain regulated and with low harmonic distortion [7].The required rating of series active filter is much smaller than that of a conventional shunt active filter [3].

Controllers are the most significant part of the UPQC and currently various control strategies are proposed by many researchers [8-11]. Here, reference current and voltage extraction from the distorted mains is by modified synchronous reference frame technique. Fuzzy logic control methodology has been demonstrated to allow solving uncertain and vague problems [12].In this paper fuzzy logic controller is used for generation of switching pulses for PWM controllers. The advantage of using fuzzy system are simplicity, case of application, flexibility, speed and ability to deal with imprecision and uncertainties. Due to absorbing and supplying of active and reactive power in active filter, the capacitance voltage is not maintained constant. In literature many controllers are used for capacitance balancing, such as PI, PID, fuzzy logic controller[28]. In

this paper fuzzy control algorithm is used to balance the dc voltage of capacitance in order to improve the performance of controller [13].The proposed method is evaluated and tested under non sinusoidal source voltage conditions using Mat lab/Simulink software.

2. Material and Methods

The UPQC consists of two voltage source inverters connected back to back with each other sharing a common dc link [9].The General UPQC block diagram is shown in Fig.1.
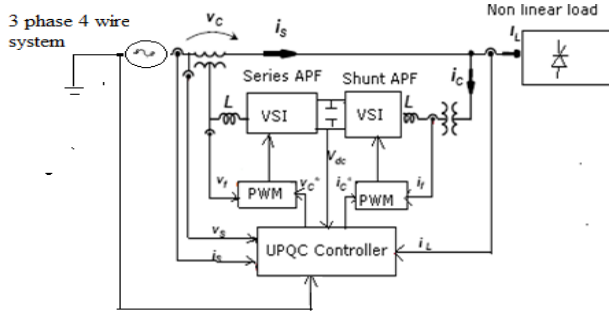

Fig.1. UPQC block Diagram.

2.1 MPLL

In series APF the inverter injects a voltage in series with the line which feeds the polluting load through a series transformer[19]. The injected voltage will be mostly harmonics with small amount of sinusoidal component in the injected voltage results a right amount of active power to compensate losses which maintains D.C voltage as constant. The series APF control algorithm calculates the reference value to be injected by the series APF transformers. The performance of the series APF depends on the phase angle which is synchronously with the supply voltage. The algorithm for detecting phase angle is based on the algorithm of coulon oscillator [27]. The harmonic rich input voltage and current signal represented by

$$x(t) = \sum_{j=1}^{M} A_j \, Sin(\omega_j t + \phi_j)$$
(1)

Where M represents the order of

harmonic, A_i represents the amplitude, ϕ_i represents phase angle. The sine and cosine of the oscillating frequency signal is calculated by[33],

$$x_1(t) = \sum_{j=1}^{M} A_j \, Sin(\omega_j t + \phi_j) . Sin(\omega_r t)$$
(2)

$$x_2(t) = \sum_{j=1}^{M} A_j \, Sin(\omega_j t + \phi_j) . cos(\omega_r t)$$
(3)

The fundamental frequency is defined by $f_1 = \omega_1 / 2\pi$ and correspondingly $\omega_j = j\omega_1, \omega_r = r\omega_1$ .Where 'j' and 'r' are harmonic order. The $x_1(t), x_2(t)$ are expanded by

$$x_1(t) = \sum_{j=1}^{M} \frac{A_j}{2} \{ cos[(j-r)\omega_1 t + \phi_j] - cos[(j+r)\omega_1 t + \phi_j] \}$$
(4)

$$x_2(t) = \sum_{j=1}^{M} \frac{A_j}{2} \{ sin[(j-r)\omega_1 t + \phi_j] + sin[(j+r)\omega_1 t + \phi_j] \}$$
(5)

The oscillating frequency should be tuned as same as ω_1 in order to get the fundamental component [33], i.e. $r = j = 1$,

$$x_1(t) = \frac{A_1}{2} \cos(\phi_1) - \frac{A_1}{2} \cos(2\omega_1 t + phj_1) + \sum_{j=1}^{M} \frac{A_j}{2} \{ cos[(j-1)\omega_1 t + \phi_j] + cos[(j+)\omega_1 t + \phi_j] \}$$
(6)

$$x_2(t) = \frac{A_1}{2} \sin(\phi_1) - \frac{A_1}{2} \sin(2\omega_1 t + phj_1) + \sum_{j=1}^{M} \frac{A_j}{2} \{ sin[(j-1)\omega_1 t + \phi_j] + sin[(j+1)\omega_1 t + \phi_j] \}$$
(7)

In the above equation the first term represents the fundamental component, the remaining terms represents the second order and further higher order harmonics. The dc component of each signal is derived from low pass filter, which is given by

$$v'_d = \frac{A_1}{2} \cos(\phi_1) \tag{8}$$

$$v'_q = \frac{A_1}{2} \sin(\phi_1) \tag{9}$$

The output can be derived by

$$A_1 = \sqrt{(2v_d')^2 + (2v_q')^2} \tag{10}$$

$$\phi_1 = tan^{-1}(v_q'/v_d') \tag{11}$$

2.2 Reference voltage signal generation of series APF

The d and q component of supply voltage is derived from input three phase supply,the phase angle for synchronization of input voltage is derived from MPLL.

$$\begin{bmatrix} V_{s0} \\ V_{sd} \\ V_{sq} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} & \sqrt{\frac{1}{2}} \\ sin(\omega t) & sin(\omega t - 2\frac{\pi}{3}) & sin(\omega t + 2\frac{\pi}{3}) \\ cos(\omega t) & cos(\omega t - 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$
(12)

The voltage in d axes (V_{sd}) given in (12) consists of Average and oscillating components of source voltages $\overline{Vsd}$, $\widetilde{Vsd}$. The oscillating component of voltage includes harmonics, the average ge (dc component v_{Sd})is calculated by applying d axis voltage (V_{sd}) to second order LPF (low pass filter)

$$V_{sd} = \overline{Vsd} + \widetilde{Vsd} \tag{13}$$

The load side reference voltages V^*_{Labc} are calculated as given in equation (14). The switching signals are assessed by comparing reference voltages V^*_{Labc} and the load voltages V_{Labc} via fuzzy logic controller.

$$\begin{bmatrix} V^*_{La} \\ V^*_{Lb} \\ V^*_{Lc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sqrt{\frac{1}{2}} & sin(\omega t) & cos(\omega t) \\ \sqrt{\frac{1}{2}} & sin(\omega t - 2\frac{\pi}{3}) & cos(\omega t - 2\frac{\pi}{3}) \\ \sqrt{\frac{1}{2}} & sin(\omega t + 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} 0 \\ \overline{V}_{Sd} \\ 0 \end{bmatrix}$$
(14)

Three-phase load reference voltages are compared with load line voltages and errors are then processed by fuzzy logic controller to generate the required switching signals for series APF IGBT switches[17].

2.3 Reference current signal generation of shunt APF

The parallel APF described in this paper is used to compensate the current harmonics, reactive power generated by the nonlinear load. The source currents are transformed to $d-q-0$ coordinates, as given in (18) using (15) and the phase angle for synchronization is achieved by taking ωt from the MPLL. In 3P4W systems and nonlinear load conditions, the instantaneous source currents $(i_{sd}$ and $i_{sq})$ include both oscillating components $(\widetilde{i_{sd}}$ and $\widetilde{i_{sq}})$ and average components $(\overline{i_{sd}}$ and $\overline{i_{sq}})$. The oscillating components consist of the harmonic and negative-sequence components of the source currents[16]. The average components consist of the positive-sequence components of current and correspond to reactive currents. The negative sequence component of source current (i_{S0}) appears when the load is unbalanced. The negative and zero sequence component must be made to 0 for compensate harmonics and unbalances and assign average component $(\overline{i_{sd}})$ in d axis [20].

$$\begin{bmatrix} i_{s0} \\ i_{sd} \\ i_{sq} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ sin(\omega t) & sin(\omega t - 2\frac{\pi}{3}) & sin(\omega t + 2\frac{\pi}{3}) \\ cos(\omega t) & cos(\omega t - 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} i_{sa} \\ i_{sb} \\ i_{sc} \end{bmatrix} \tag{15}$$

In order to compensate the active power losses of the UPQC power circuit during the active power is injected to the power system by the series APF, which causes dc-link voltage reduction[14].In parallel APF, the active power is absorbed from the power system for regulating dc-link voltage. Due to absorption and injection of active power, the dc link voltage is not maintained constant for this purpose, the dc-link voltage is compared with its reference voltage (v_{dc}), and the required active current (i_{dloss}) is obtained by a fuzzy logic controller. Compare to all other controller like PI, PID controllers, the dynamic performance of fuzzy logic controller is good.This controller is used to control the dc side capacitor voltage of the PWM-inverter [24].

The source current fundamental reference component is calculated by adding to the required active current and source current average component $(\overline{i_{sd}})$, which is obtained by an LPF, as given in equation.16.

$$i_{sd\_ref} = i_{dloss} + \overline{i_{sd}} \tag{16}$$

The source current references are calculated as given in (17) to compensate the harmonics, neutral current, unbalance, and reactive power by regulating the dc-link voltage [27].

$$\begin{bmatrix} i_{sa\_ref} \\ i_{sb\_ref} \\ i_{sc\_ref} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sqrt{\frac{1}{2}} & sin(\omega t) & cos(\omega t) \\ \sqrt{\frac{1}{2}} & sin(\omega t - 2\frac{\pi}{3}) & cos(\omega t - 2\frac{\pi}{3}) \\ \sqrt{\frac{1}{2}} & sin(\omega t + 2\frac{\pi}{3}) & cos(\omega t + 2\frac{\pi}{3}) \end{bmatrix} \begin{bmatrix} 0 \\ \overline{i_{sd}} \\ 0 \end{bmatrix}$$

(17)

The produced reference-source currents (i_{sa_ref}, i_{sb_ref}, and i_{sc_ref}) and measured source currents (i_{sa}, i_{sb}, and i_{sc}) are compared by a fuzzy logic current controller for producing IGBT switching signals to compensate all current-related problems, such as the reactive power, current harmonic, neutral current, dc-link voltage regulation, and load-current unbalance. The generation of reference voltage and current is shown in Figs.2,3.
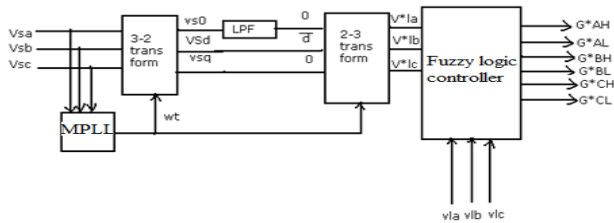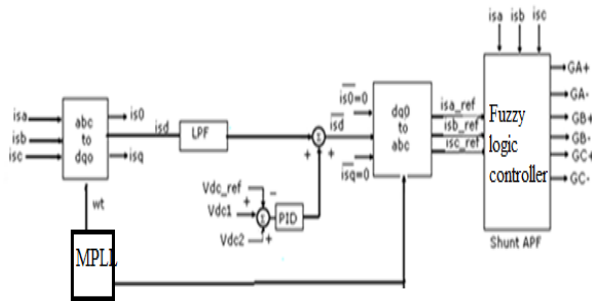

Fig.2. Reference voltage generation

Fig.3. Reference current generation

3. Control strategy

The performance of UPQC depends on the characteristic of the active filters. Many current controlled stratergies are proposed for APF application [18][21-23]. For easy implementation and quick response HCC is used. But HCC has some disadvantage like output current distortion and higher switching losses. This problem is eliminated by fuzzy logic controller, which enables taking a decision even if we are not estimate inputs. The fuzzy logic controller is used in almost all sectors of industry and power systems and science and one among them is harmonic current and reactive power compensation [25].In this paper fuzzy logic controller is used to generate switching pulses shown in Fig.4.
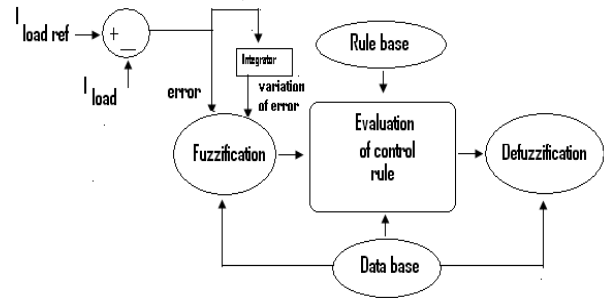

Fig.4. Fuzzy logic controller general diagram.

The fuzzy logic controller has 5 main parts. They are fuzzification, Defuzzification, rule base database, evaluation of control rule. In fuzzification module the control inputs i.e. error signal, and its variation converted into fuzzy variable. In rule evaluator basic three fuzzy set operations are used(AND,OR,NOT). In defuzzification module the linguistic variables are converted into real values. The data base module stores the membership function. The rule base stores the linguistic control required by rule evaluator [26],[28]. The following rules are used for gate pulse generation.

1.If Error is zero, then output command is zero.
2.If Error is positive , then output command is big positive.
3. If Error is negative then output command is big negative .
4. If Error is 0 and d/dt of Error is positive, then output command is negative.
5. If Error is 0 and d/dt of Error is negative , then output command is positive.

4. Capacitance voltage balancing

The Dc voltage is sensed and compared with reference value for capacitance balancing in order to reduce the energy loss. The compared error is passed to PI controller for getting constant value. The effectiveness of the control technique is improved by fuzzy logic controller. Fuzzy logic is characterized by seven fuzzy sets as a input and output variable and 49 rules are formed, triangular membership function is used for the simplicity, mamdani min type is used as a implication, defuzzification using by the height method. Fig.5. shows fuzzy controller diagram.
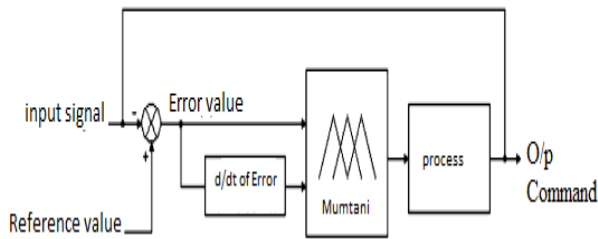
Fig.5. Fuzzy Logic Controller

The table 4.1 shows the fuzzy base rule.

error(e)	change in error(Δe)						
	NH	NM	N S	Z	PS	PM	PH
NH	NH	NH	NH	NH	NM	NS	Z
NM	NH	NH	NH	NM	NS	Z	PS
NS	NH	NH	NM	NS	Z	PS	PM
Z	NH	NM	NS	Z	PS	PM	PH
PS	NM	NS	Z	PS	PM	PH	PH
PM	NS	Z	PS	PM	PH	PH	PH
PH	Z	PS	PM	PH	PH	PH	PH

5. Simulation results

In this study, fuzzy logic based control algorithms for the UPQC are evaluated using simulation results given in Matlab/Simulink software. This system compensates the current harmonics produced by a diode bridge rectifier and eliminates the voltage harmonics under unbalance load condition. 3P4W UPQC system consists of two voltage controlled inverters (shunt and series APFs) sharing the same dc bus

in split-capacitor topology. The series APF is connected in series with the neutral conductor via a ripple RC filter, R_T and C_T, and a matching Series transformer. The dc links of both shunt and series APFs are connected to two common series 2200-μF dc capacitors under 700-V dc in split capacitor topology. A three-phase and a single-phase diode bridge rectifier are used as nonlinear loads and the effect of change in load current is recorded for each phase. The control algorithm for the UPQC is evaluated by Matlab/Simulink software. The system is investigated under unbalanced load conditions. The system parameters used are Line to line source voltage V $_{rms}$is 380V; System frequency (f) is 50 Hz; Source inductance is L_S is 1 m H; Series side Filter impedance of R_{c1}, L_{c1}, C_{c1} is 100 Ω,1μH,60μF; Shunt side Filter impedance of R_{c2}, L_{c2}, C_{c2} is 5Ω, 3.5mH, 10μF; three phase diode rectifier R_L, L_L load: 10 Ω; 30 m H respectively; Unbalanced three phase load resistances are R1 = 20 Ω, R2 = 70 Ω, R3 = 100 Ω and Load inductance L_L is 50 mH; DC side capacitance is 2200 μF; Reference voltage ($V_{DC,ref}$) is 700V,switching frequency of series and shunt inverter is approximately12 KHz.

5.1. UPQC Off condition

The fig.6(a) indicates source voltage before compensation. The diode-rectifier load current or source current before compensation is shown in Fig.6(b). The Neutral current is shown in Fig.6(c). The THD of the Source Voltage and Current before compensation is 26.6% and 29.7%.
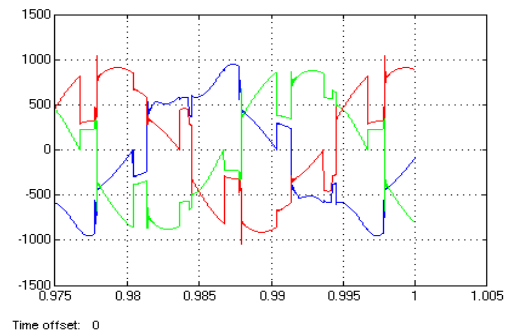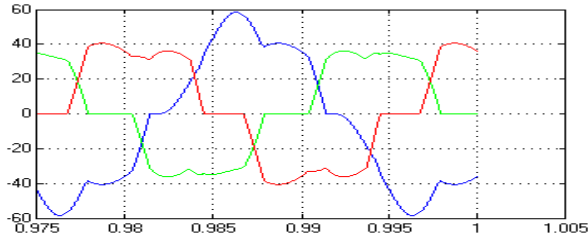

Fig.6 (a). Source voltage (UPQC OFF)

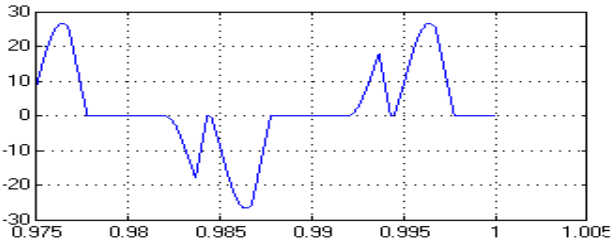Fig.6(b). Source current (UPQC OFF)

Fig.6(c). Neutral current (UPQC OFF)

5.2 UPQC ON condition

The source voltage after compensation in Fig.7 (a), this figure indicates the current is sinusoidal. The source current after compensation is presented is presented in Fig.7 (b) this indicates the input supply current is sinusoidal. The APF is suppressing reactive/harmonic power and simultaneously improves power factor. The neutral current of UPQC is presented in Fig. 7(c).
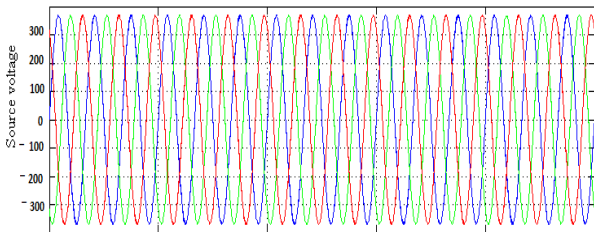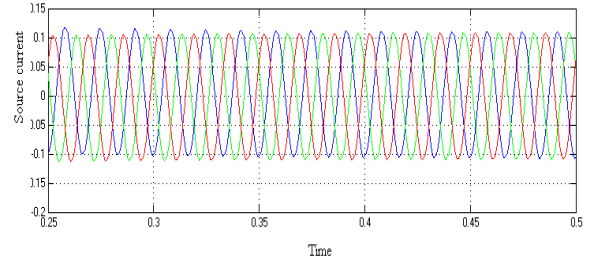

Fig.7 (a) Source voltage (UPQC ON)
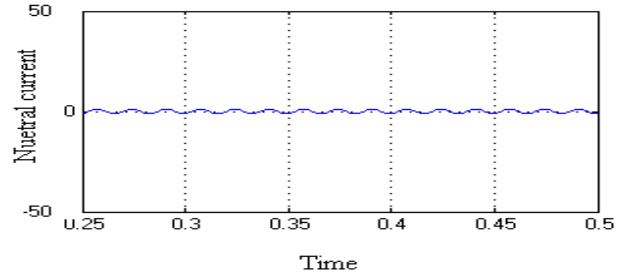

Fig.7 (b). Source current (UPQC ON)

Fig.7(c). Neutral current (UPQC ON)

The Fast Fourier Transform (FFT) is used to measure the order of harmonics in source voltage, source current. The FFT analysis of the active filter confirms that the THD of the source current is less than 5% that is in compliance with IEEE-519 and IEC 61000-3 harmonic standards.

5.3 Experimental setup

A proto type test system of UPQC was set up in the laboratory to test the validity of the control algorithms of series and shunt active filters. The experimental system consists of three important parts: the supply system, the load unit and the active power filters. The power mains supply is a 415 V three-phase power supply, which is available in the laboratory. A three phase variac is used to vary supply voltage for experimentation. Normal circuit breakers and fuses are used to The load unit consists of a 3-phase rectifier and unbalanced resistive load. The unbalanced three phase load resistances are $R_1 = 20\ \Omega$, $R_2 = 70\ \Omega$, $R_3 = 100\ \Omega$ and Load inductance L_L is 50 mH. The control unit of hardware setup consists of an ATMEL 89S52 microcontroller along with the driver circuit. to perform switching operation and the pulses are

fed to the microcontroller. The Fig.8 shows source current and voltage after compensation from experiment setup.Fig.9 shows THD of source current and voltage.
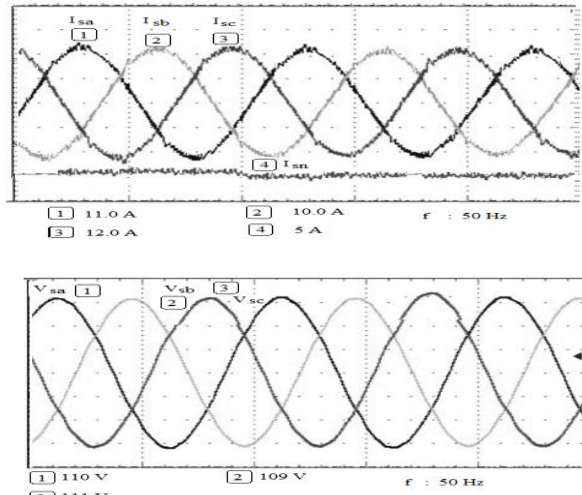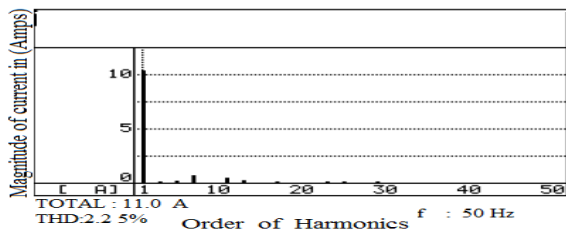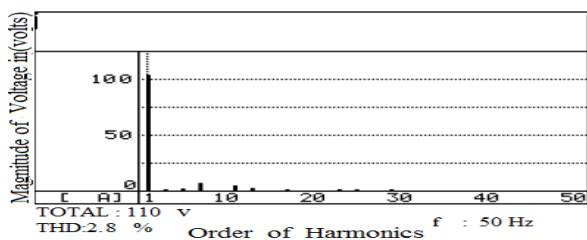

Fig.8 Experimental source current, Neutral current and source voltage

a) THD of source current

b) THD of source voltage

Fig.9 Experimental THD of a)source current and b)source voltage

6. Conclusion

This paper describes the UPQC, which mainly compensates the reactive power along with voltage and current harmonics under unbalanced load conditions. In both Active filters, the reference voltage, current are generated by MPLL method and gate pulse generated by fuzzy logic based current controllers are used for gate pulse generation. The series APF isolates the loads and source voltage in unbalanced and distorted load conditions and the parallel APF compensates reactive power, neutral current, and harmonics and provides three-phase balanced and rated currents for the mains. The proposed UPQC is validated using extensive Matlab simulation and hardware setup. THD of source current and voltage are found to be 2.25 % and 2.8%. In both methods, the measured total harmonic distortion of the source current and voltage are low in compliance with IEEE 519 and IEC 61000-3 harmonic standards.

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