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Control of UPQC to Alleviate Power Quality Problems by Symmetrical Components Method

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***Abstract*—This paper presents a symmetrical component method to control the series APF and shunt APF of UPQC to alleviate the power quality problems like voltage sag/ swell, voltage unbalance, current and voltage harmonics. In Electrical power distribution system, at point of common coupling the UPQC can enhance the power quality under distorted conditions. MATLAB/ SIMULINK based results are presented in detailed to reinforce the symmetrical component method.**

Keywords*— Power quality(PQ); Active power filter(APF); Unified power quality conditioner (UPQC); symmetrical component theory (SCT); Voltage sag/swell; Voltage harmonics; current harmonics;

I. INTRODUCTION

The concerned about the term power quality are becoming increasingly in both electric utilities and end users of electric power industry is due to the following reasons

1. Microprocessor-based controls, power electronic devices, Newer-generation load equipment are more sensitive to power quality problems..
2.To improve overall power system efficiency usage of power electronic based systems like FACT devices, shunt capacitor for power factor correction and reactive power compensation are increased there by injection of harmonics into the system is also increased.
3. Increment of awareness of power quality at end users to operate their electrical equipment at high efficiency and safely.
4. Interconnecting of renewable energy sources to the grid system at time of synchronization

The main reason that we are concentrating on power quality is economic value. On electric utilities, customers and suppliers of the load equipment has direct impact. The quality of power can have a direct economic impact on many industrial consumers. There has recently been a great emphasis on revitalizing industry with more automation and more modern equipment.

The various types of power quality problems are short/long duration voltage variations like voltage sag, voltage swells, interruptions, under voltages, over voltages, harmonics, transients etc… In the above power quality problems, the voltage sags and swells are the most important power quality problems. So in order to mitigate these sags and swells of voltages we have to approaches i, e... load conditioning and line conditioning.

The solutions for power quality problems can be done from load side are called load conditioning.
The following are the different ways of load conditioning
1) UPS a) Online UPS
b) Standby UPS
c) Hybrid UPS
2) Stabilizers,
3) Motor-Generator sets,
4) Active series compensators etc…
The solutions for power quality problems can be done from utility or line side are called line conditioning.
The following are the different ways of load conditioning
a) Fact control devices
b) Shunt active filters
c) Series active filters
b) Custom power devices
1) Shunt active filters
2) Series active filters
3) Dynamic voltage restorer
4) D-Statcom
5) UPFC (Unified power flow controller)
6) UPQC (Unified power quality conditioner)

One of the effective approaches is to use a unified power quality conditioner (UPQC) at PCC to protect the sensitive loads.

II. SYSTEM CONFIGURATION

The configuration for Unified Power Quality Conditioner is shown in the Fig.1. At Point of Common Coupling the voltage may be or may not be distorted depending on the non-linear loads connected at PCC. Also, these loads may impose the voltage sag or swell condition during their switching ON and/or OFF operation. The UPQC is installed in order to protect a sensitive load from all disturbances.

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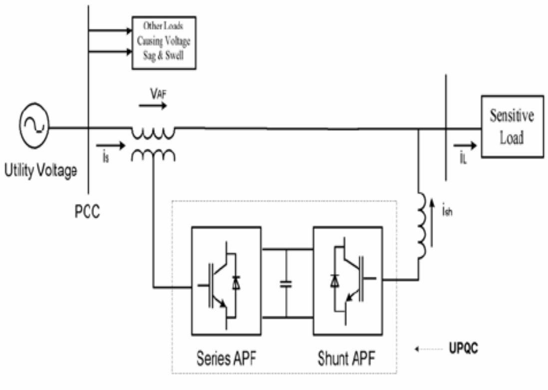

Fig 1. Block diagram of UPQC

The UPQC consists of two voltage source APF connected back to back, sharing a common dc link. Each APF is realized by using six IGBT switches. One APF is connected parallel with the load, acts as shunt APF, helps in compensating load harmonic current, reactive current and maintain the dc link voltage at constant level. The second APF is connected in series with the line using series transformers, acts as a controlled voltage source maintaining the load voltage sinusoidal and at desired constant voltage level.

III. MODEL OF UPQC

The per phase equivalent circuit for a 3 phase UPQC is shown in the Fig. 2.

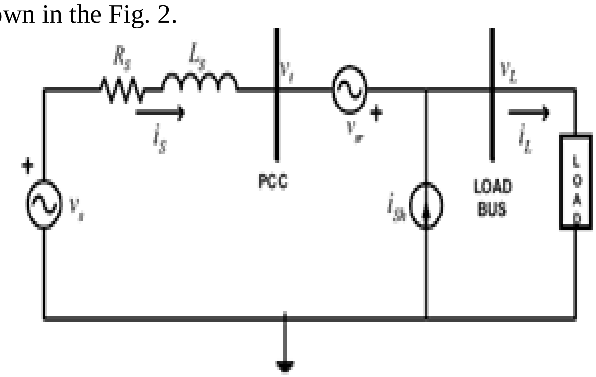

Fig 2. Equivalent Circuit of a UPQC

The terminal voltage, source voltage, at Point of common coupling and load voltage are denoted by v_s, v_t and v_L respectively. The source and load currents are denoted by i_s and i_L respectively. The injected voltage by series APF is denoted by v_{Sr}, whereas the injected current by shunt APF is denoted by $i_{Sh.}$ Taking the load voltage, v_L, as a reference phasor and suppose the lagging power factor of the load is $Cos_{\varphi L}$ then we can write

$$\overline{V_L} = V_L\angle 0^0 \quad 1$$

$$\overline{I_L} = I_L\angle -\emptyset_L \quad 2$$

$$\overline{V_t} = V_L(1+K)\angle 0^0 \quad 3$$

Where factor k represents the fluctuation of source voltage, defined as,

$$k = \frac{V_t - V_L}{V_L}$$

4

The voltage injected by series APF must be equal to,

$$\overline{V_{sr}} = \overline{V_L} - \overline{V_t} = -kV_L\angle 0^0$$

5

The UPQC is assumed to be lossless and therefore, the active power demanded by the load is equal to the active power input at PCC. The UPQC provides a nearly unity power factor source current, therefore, for a given load condition the input active power at PCC can be expressed by the following equations,

$$P_t = P_L \quad 6$$

$$V_t i_s = V_L i_s \cos\emptyset_L$$

7

$$V_L(1+k)i_s = V_L i_s \cos\emptyset_L$$

8

$$i_s = \frac{i_L}{(1+k)}\cos\emptyset_L \quad 9$$

The above equation suggests that the source current i_S depends on the factor k, since φ_L and i_L are load characteristics and are constant for a particular type of load. The complex power absorbed by the series APF can be expressed as,

$$\overline{S_{sr}} = \overline{V_{sr}} i_s \quad 10$$

$$P_{sr} = V_{sr} i_s \sin\emptyset_s = -kV_L i_s \cos\emptyset_s$$

11

$$Q_{sr} = V_{sr} i_s \sin\emptyset_s$$

12

$\emptyset_S$ =0, since UPQC is maintaining unity power factor

$$P_{sr} = V_{sr} i_s = -kV_L i_s \quad 13$$

$$Q_{sr} = 0 \quad 14$$

The complex power absorbed by the shunt APF can be expressed as,

$$\overline{S_{sh}} = \overline{V_L}.i_{sh}^* \quad 15$$

The current provided by the shunt APF, is the difference between the input source current and the load current, which includes the load harmonics current and the reactive current. Therefore, we can write;

$$\overline{\iota_{sh}} = \overline{\iota_s} - \overline{\iota_L} \quad 16$$

$$\overline{\iota_{sh}} = \overline{\iota_s}\angle 0^0 - \overline{\iota_L}\angle -\emptyset_L \quad 17$$

$$\overline{\iota_{sh}} = i_s - (i_L\cos\emptyset_L - j\, i_L \sin\emptyset_L) \quad 18$$

$$\overline{\iota_{sh}} = ((i_s - (i_L\cos\emptyset_L)) + j i_L \sin\emptyset_L)$$

19

$$P_{sh} = V_L i_{sh}\cos\emptyset_{sh} = V_L(i_s - i_L\cos\emptyset_L) \quad 20$$

$$Q_{sh} = V_L i_{sh}\sin\emptyset_{sh} = V_L i_L \sin\emptyset_L \quad 21$$

IV CONTROLLERS

A. Control Scheme of Series Active Filter

The control method of series APF consists of determination reference load terminal voltages ($V_{la}^*, V_{lb}^*, V_{lc}^*$). Using the estimated reference voltages, the series filter is controlled such that to injects voltages (V_{ca}, V_{cb}, V_{cc}) which cancel out the distortions and/or unbalance present in the supply voltages (V_{sa}, V_{sb}, V_{sc}), thus making the voltage at PCC (V_{la}, V_{lb}, V_{lc}) as perfectly balanced and sinusoidal with desired amplitude. In other words, the sum of supply voltage and injected series filter voltage makes the desired voltage at load terminals.

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The control algorithm followed using symmetrical components is depicted in Fig.3. Three-phase distorted/unbalanced supply voltages (v_{sa}, v_{sb}, v_{sc}) are sensed and are transformed using symmetrical components transformation matrix as

$$\begin{pmatrix} v_{a1} \\ v_{a2} \\ v_{a3} \end{pmatrix} = \frac{1}{3}\begin{pmatrix} 1 & a & a^2 \\ 1 & a^2 & a \\ 1 & 1 & 1 \end{pmatrix}\begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix} \qquad 22$$

The voltages v_{a1}, v_{a2} *and* v_{a0} stand for positive, negative and zero sequence components of phase to neutral voltage of phase 'a' respectively. After transforming to instantaneous symmetrical components, v_{a1} is processed through a band pass filter (BPF) to eliminate any harmonics present in the voltage and is denoted as $V_m \sin\theta$. This voltage is processed through a differentiator to get $V_m \cos\theta$ and these quantities are converted to three phase quantities as

$$\begin{pmatrix} v_x \\ v_y \\ v_z \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix}\begin{pmatrix} v_m \sin\theta \\ v_m \cos\theta \end{pmatrix} \qquad 23$$

The amplitude of these voltages (v_x, v_y, v_z) is computed as

$$v_m^1 = \sqrt{\left(\frac{2}{3}\left(v_x^2 + v_y^2 + v_z^2\right)\right)}$$

24

Supply in phase 120^0 displaced, three unit vectors (u_a, u_b, u_c) are calculated by dividing v_x, v_y, v_z with their amplitude V_m^1. The computed three in phase unit vectors are then multiplied with the desired peak value of PCC phase voltage (v_{lm}^*), which become the three phase reference PCC voltage ($v_{la}^*, v_{lb}^*, v_{lc}^*$) as given in eqn 25. The computed three in phase unit vectors are then multiplied with the desired peak value of PCC phase voltage (v_{lm}^*), which become the three phase reference PCC voltage ($v_{la}^*, v_{lb}^*, v_{lc}^*$) as

$$\begin{pmatrix} v_{la}^* \\ v_{lb}^* \\ v_{lc}^* \end{pmatrix} = v_{lm}^* \begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} \qquad 25$$

The computed voltages are then given to hysteresis controller along with the sensed three phase PCC voltages, which generates the switching signals such that the voltage at the PCC terminal becomes the desired sinusoidal reference voltage.

B. Control Scheme of Shunt Active Filter

The control algorithm of shunt AF consists of generation of three-phase reference supply currents ($i_{sa}^*, i_{sb}^*, i_{sc}^*$) and is depicted in Fig. 4. This algorithm uses the supply in phase, 120^0 displaced three unit vectors (u_a, u_b, u_c) computed using symmetrical components control scheme. The amplitude of reference supply current (I_{sp}^*) is computed as follows. Comparison of average and reference values of dc bus voltage of the AF results in a voltage error, which is fed to a PI controller and the output of PI controller, is taken as amplitude of the reference supply currents(I_{sp}^*). Three in-phase reference supply currents are computed by multiplying their amplitude and in-phase unit current vectors as

$$\begin{pmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{pmatrix} = I_{sp}^* \begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} \qquad 26$$

The computed three phase supply reference currents are compared with sensed supply currents (i_{sa}, i_{sb}, i_{sc}) and are given to a hysteresis controller to generate the switching signals to the switches of the shunt AF which makes the supply currents to follow its reference values. Hence the supply currents contain no harmonic and reactive power components. In this, the current control is applied over fundamental supply currents instead of fast changing AF currents, thereby reducing the computational delay and number of sensors required.

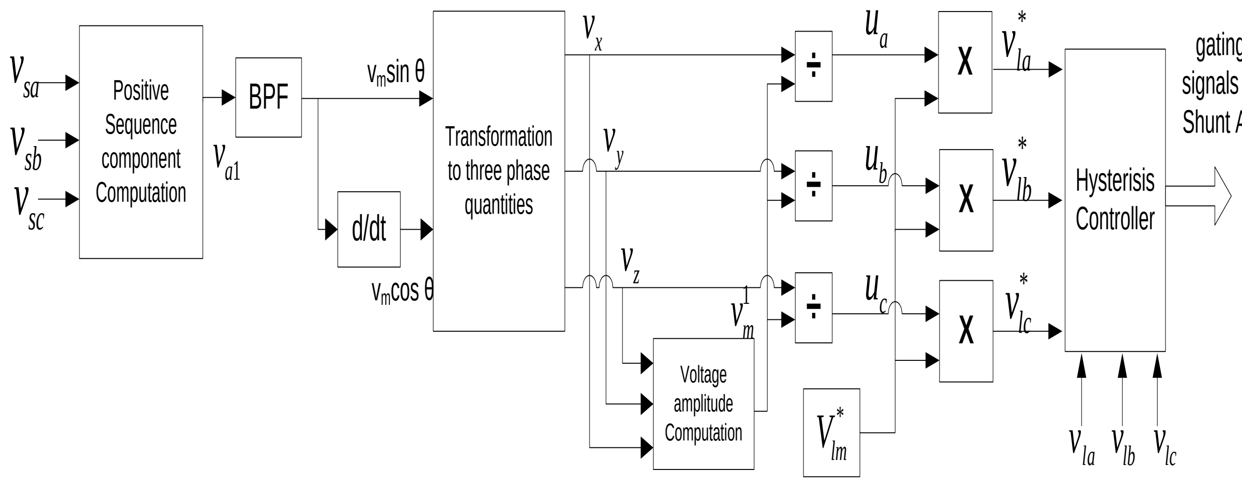

Fig 3. Reference Voltage signal generation for the series APF of UPQC

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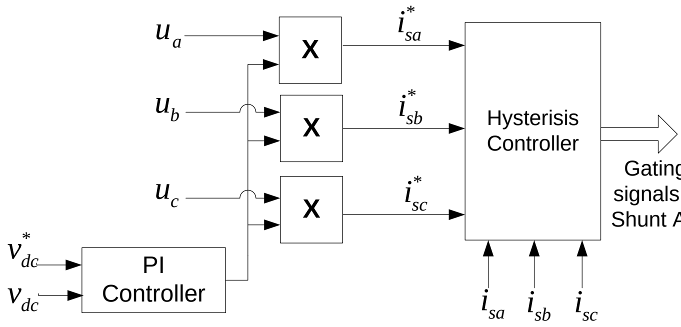

Fig 4. Reference current generation for the shunt APF of UPQC

V SIMULATION RESULTS

The Performance of the UPQC with symmetrical component theory control for compensation of voltage sag, voltage swell, and unbalanced supply in the power system has been analyzed by simulation. the source is assumed to be pure sinusoidal. The supply voltage which is available at UPQC terminal is considered as three phase, 50 Hz, 415 V (line to line)
with the maximum load power demand of 6 kW + j 3 kVAR (load power factor angle of 0.0.952 lagging).

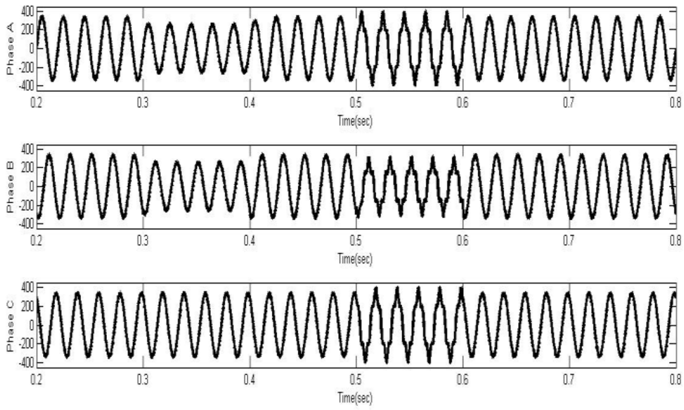

Fig.5. Source Voltage

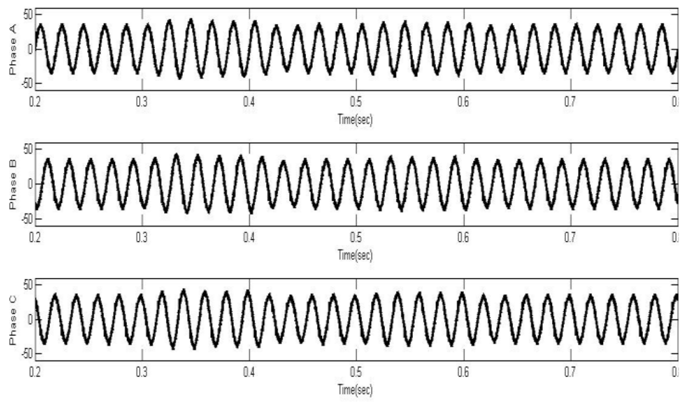

Fig.6. Source Current

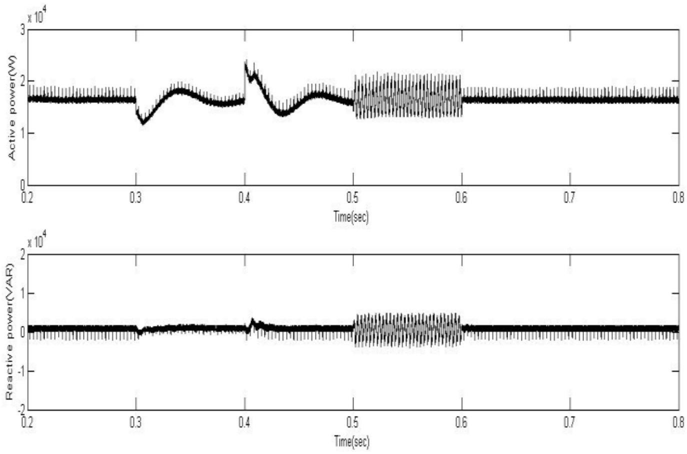

Fig.7. Source active power and reactive power

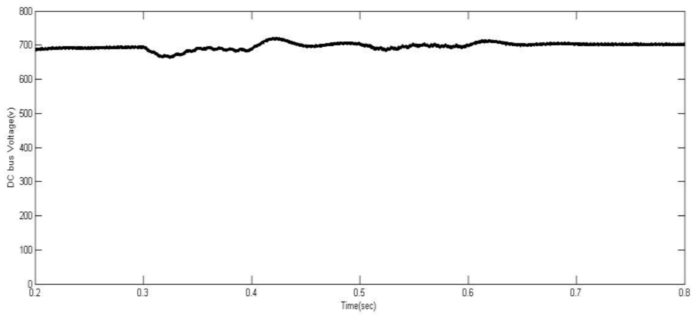

Fig.8.Dc bus Voltage

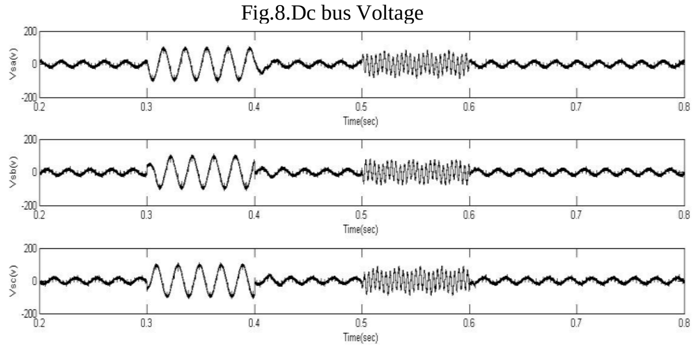

Fig.9.Injected voltage of series APF

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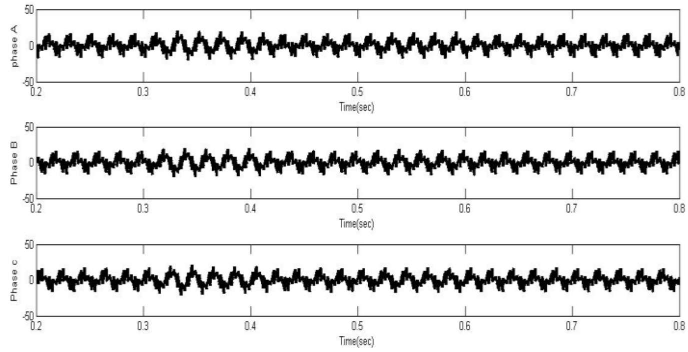

Fig.10.Shunt APF currents

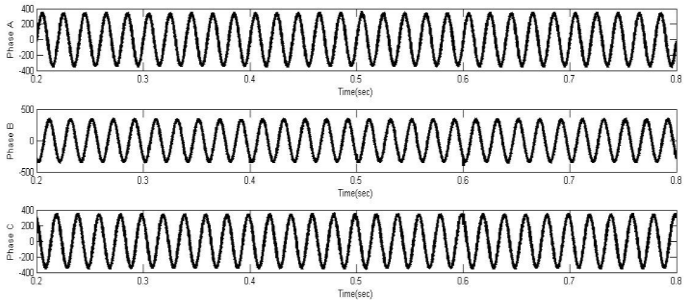

Fig.11.Load voltages

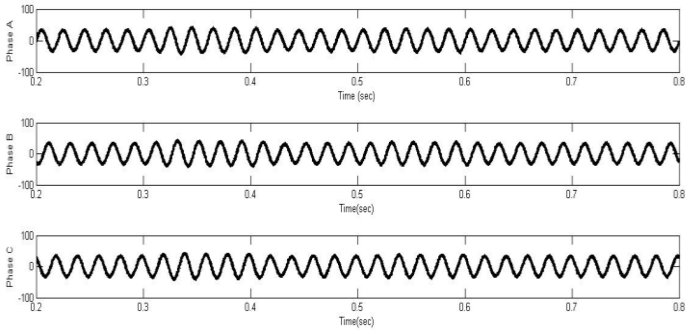

Fig.12.Load Currents

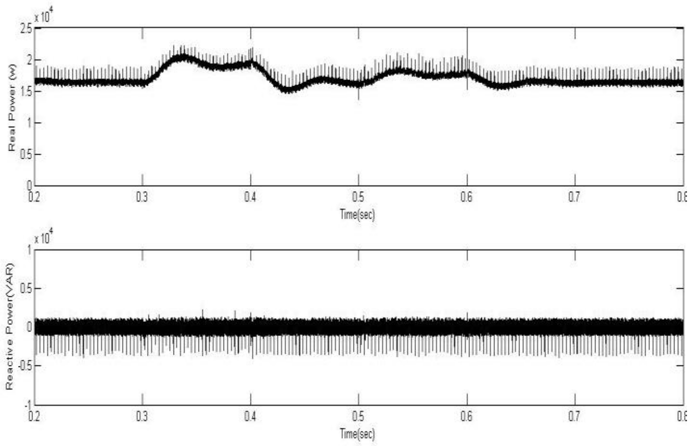

Fig. 13. Load real and Reactive powers

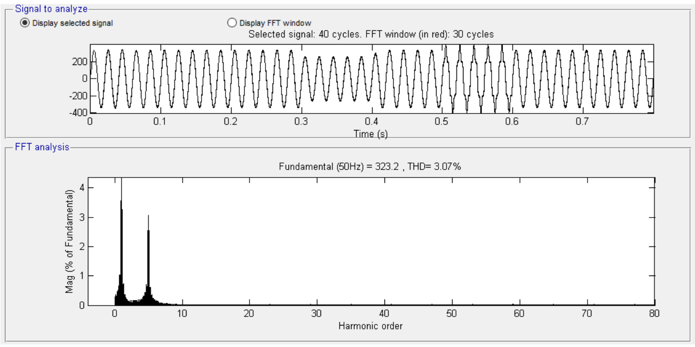

Fig .14.THD of Source voltage

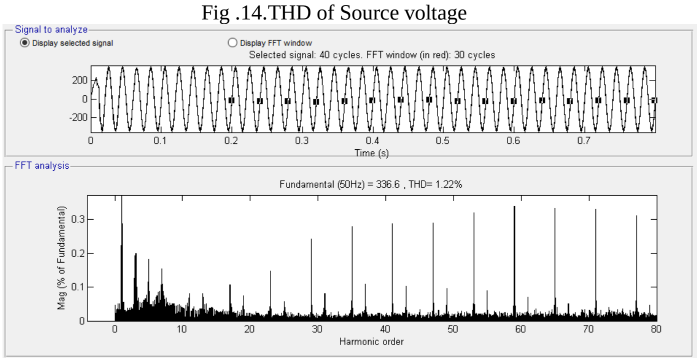

Fig.15. THD of load voltage

Fig 5 shows the source volatge with sag for time period of 0.3 to 0.4sec and with a swell for time period 0.5 to 0.6 sec. During these disturbance time periods the UPQC maintain the constant voltage at load terminals. Fig 8 shows the dc link capacitor voltage as constant. Fig 9 shows the injection of voltages by series APF to compensate the voltage sag/swell in the system.

Fig 7 and 13 shows the Active and Reactive powers od source and load under normal conditions, sag and swell conditions.

Fig 14 and 15 Shows the THD levels at source side and load side volatages as 3.07% and 1.22% with UPQC.

VI CONCLUSION

In this paper the symmetrical component theory is used to generate the reference voltage signals for series APF and reference current signals for shunt APF of UPQC to mitigate the voltage sags /swells and harmonics in the system. The effectiveness of UPQC has been demonstrated in maintaining three phase balanced sinusoidal reference load voltage, harmonic voltage elimination.

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