

# Simulation and Performance Investigation of Unified Power Quality Conditioner Using Hysteresis Current Control Method

Vikash Anand, Dr.S.K.Srivastava

**Abstract** - The simulation study of hysteresis controlled three phase unified power quality conditioner (UPQC) to improve power quality by compensating harmonics and reactive power required by a non-linear load is presented. UPQC consists of back to back connected Series And Shunt Active Filters, and is modeled with reference to a synchronously rotating d-q-o reference axes. The shunt active power filter compensates the source current harmonics and also it maintains the dc link voltage unchanged in steady state, while the series active power filter compensates the load voltage harmonics. This paper has proposed auto tuned UPQC maintains the THD well within the IEEE-519 standards. The results are found to be quite satisfactory to mitigate harmonics distortion, reactive power compensation and power factor improvement.

**Keywords** – Power System, Shunt Active Filter, Series Active Filter, Hysteresis Current Pulse Width Modulation.

## 1 INTRODUCTION

Harmonics contamination is a serious and a harmful problem in electric power system. Active power filtering constitutes one of the most effective proposed solutions. A UPQC that achieves low source current harmonics, low load voltage total harmonic distortion (THD), reactive power compensation and power factor correction is presented. Hence, it is necessary to reduce the dominant harmonics below 5% as specified in IEEE-519-1992 harmonic standard [9].

Harmonic Amplification is one the most serious problem. It is caused by harmonic resonance between line inductance and power factor correction (PFC) capacitors installed by consumers. Active filters for damping out harmonic resonance in industrial and utility power distribution systems have been researched [9]-[7].

Traditionally based, passive L-C filters were used to eliminate line harmonics in [1]-[13]. However, the passive filters have the demerits of fixed compensation, bulkiness and occurrence of resonance with other elements. The recent advances in power semiconductor devices have resulted in the development of active power filters (APF) for harmonic suppression.

(RDFT) based methods. The frequency domain methods require large memory, computation power and the results provided during the transient condition may be imprecise [13]. There are several current control strategies proposed in the literature [7]-[2], [12]-[3], namely, PI control, Average Current Mode Control (ACMC), Sliding Mode Control (SMC) and hysteresis control. Among the various current control techniques, hysteresis control is the most popular one for active power filter applications. Hysteresis current control is a method of controlling a voltage source inverter so that the output current is generated which follows a reference current waveform in this paper[10].

In this paper, the proposed control algorithm for UPQC is applicable to harmonic voltage source loads as well as to harmonic current source loads. This control algorithm is applied under the basic concept of the generalized d-q-o theory. However, this generalized d-q-o theory is valid for compensating for the harmonics and reactive power using the parallel active power filter in the three-phase power system. To overcome such limits, a revised d-q-o theory is proposed. This revised algorithm may be effective not only for the three-phase three-wire UPQC with harmonic current, voltage loads, but also for the combined system of parallel passive filters and active filter[5].

This chapter basically deals with the modeling and design of UPQC for compensation of harmonics and reactive power. Designs of different parameters like power circuit, thyristor controlled capacitor banks, series active filter and shunt active filter are discussed.

## 2 SERIES-SHUNT ACTIVE FILTER

As the name suggests, the series-shunt active filter is a combination of series active filter and shunt active filter. The topology is shown in Fig 1. The shunt-active filter is located at

- 
- **Vikash Anand**  
M.Tech.(Pursuing)-Electrical Engineering Department.  
Madan Mohan Malviya Engineering College  
Gorakhpur-273010(U.P), India  
E-mail- [svivastava.anand09@gmail.com](mailto:svivastava.anand09@gmail.com)
  - **Dr. S. K. Srivastava**  
Associate Professor-Electrical Engineering Department  
Madan Mohan Malviya Engineering College  
Gorakhpur-273010(U.P), India.  
E-mail- [sudhirsri05@gmail.com](mailto:sudhirsri05@gmail.com)

There are two major approaches that have emerged for the harmonic detection [1], namely, time domain and the frequency domain methods. The frequency domain methods include, Discrete Fourier Transform (DFT), Fast Fourier Transform (FFT), and Recursive Discrete Fourier Transform

the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology is called as Unified Power Quality Conditioner. The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter and damps power system oscillations. The shunt portion compensates load current harmonics, reactive power and load current unbalances. In addition, it regulates the dc link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator and the power required to cover losses[11].

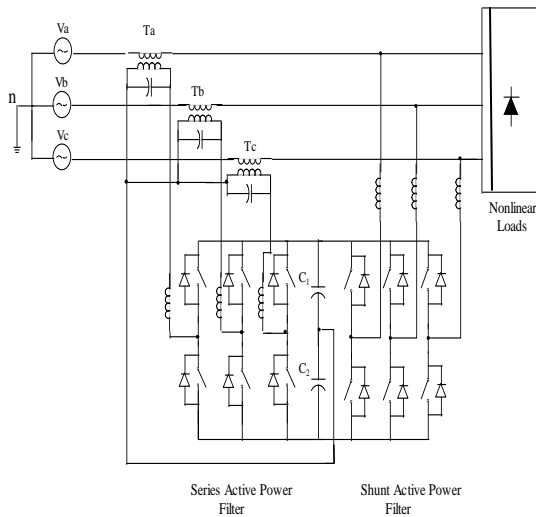


Fig 1 Unified power quality conditioner topology

### 3. UNIFIED POWER QUALITY CONDITIONER

The UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. The UPQC, therefore, is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance[4]-[3].

Elimination of supply voltage flicker, however, is accompanied by low frequency fluctuation of active power flowing into or out of series active filter. The shunt active filter performs dc link voltage regulation, thus leading to a significant reduction of capacity of dc link capacitor.

#### 3.1 Mathematical Modeling of UPQC

In this study, the power supply is assumed to be a three-phase, three-wire system. The two active filters are composed of two 3-leg voltage source inverters (VSI). Functionally, the series filter is used to compensate for the voltage distortions while the shunt filter is needed to provide reactive power and counteract the harmonic current injected by the load. Also, the voltage of the DC link capacitor is controlled to a desired value by the shunt active filter. There can be negative and zero sequence components in the supply when a voltage

disturbance occurs. The DC link capacitor bank is divided into two groups connected in series. The neutrals of the secondary of both transformers are directly connected to the dc link midpoint [4]-[6]-[5].

The power system model considered can be divided into following units: the power supply system, series active filter and shunt active filter. These constituent members of the UPQC are modeled separately in this section. First consider the power supply system. By Kirchhoff's law:

$$v_{if} = e_i - L_s \frac{di_s}{dt} - R_s i_{is} - v_{ih} \quad (1)$$

$$i_{is} = i_{iL} - i_{ih} \quad (2)$$

Where, subscript i refers to a, b and c phases in the power system;  $L_s$  and  $R_s$  are the inductance and resistance of the transmission line;  $v_{if}$  is fundamental source voltage,  $e_i$  is source voltage;  $v_{ih}$  is the output voltage (harmonic voltage) of the series active filter;  $i_{is}$  is the line current;  $i_{iL}$  is the load current and  $i_{ih}$  is the output current of the shunt of the shunt active filter respectively[2].

For the series active filter,

$$v_{ih} = L_1 \frac{di_{is}}{dt} + R_1 i_{is} + d_{1i} v_{c1} + (1 - d_{1i}) v_{c2} \quad (3)$$

Where,  $L_1$  and  $R_1$  are the leakage inductance and resistance of the series transformer,  $v_{c1}$  and  $v_{c2}$  are the voltages of dc link capacitors;  $d_{1i}$  is the switch duty ratio of the series active filter. Without loss of generality, the turn's ratio of the transformer is assumed to be unity.

For shunt active filter:

$$L_2 \frac{di_{ih}}{dt} = R_2 i_{ih} - v_{if} + d_{2i} v_{c1} + (1 - d_{2i}) v_{c2} \quad (4)$$

Where  $L_2$  and  $R_2$  are the leakage inductance and resistance of the shunt-connected transformer,  $d_{2i}$  is the switch duty ratio of the shunt active filter. The turn's ratio of this transformer is also assumed to be unity.

The two dc bus capacitor voltages can be described by the equations (5) and (6):

$$\frac{dv_{c1}}{dt} = \frac{i_{c1}}{C_1} = \frac{1}{C_1} \left( \sum_{i=a,b,c} d_{1i} i_{is} - \sum_{i=a,b,c} d_{2i} i_{ih} \right) \quad (5)$$

$$\frac{dv_{c2}}{dt} = \frac{i_{c2}}{C_2} = \frac{1}{C_2} \left[ \sum_{i=a,b,c} (1 - d_{1i}) i_{is} - \sum_{i=a,b,c} (1 - d_{2i}) i_{ih} \right] \quad (6)$$

#### 3.2 UPQC Operating Principle

Distorted voltages in a 3-phase system may contain negative phase sequence, zero phase sequence as well as harmonic components. The voltage of phase "a" can be expressed as, in general[15]:

$$v_a = v_{1pa} + v_{1na} + v_{1oa} + \sum V_{ka} \sin(k\omega t + \theta_{ka}) \quad (7)$$

Where,  $v_{1pa}$  is the fundamental frequency's positive sequence component while  $v_{1na}$  and  $v_{1oa}$  is the negative and zero sequence components. The last term of equation (7),  $\sum V_{ka}\sin(k\omega t + \theta_{ka})$  represents the harmonics in the voltage. In order for the voltage at the load terminal to be perfectly sinusoidal and balanced, the output voltages of the series active filter should be:

$$v_{ah} = v_{1na} + v_{1oa} + \sum V_{ka}\sin(k\omega t + \theta_{ka}) \quad (8)$$

It will be shown how the series active filter can be designed to operate as a controlled voltage source whose output voltage would be automatically controlled according to equation (8).

The shunt active filter performs the following functions:

- To provide compensation of the load harmonic currents to reduce voltage distortions.
- To provide load reactive power demand.
- To maintain the DC-link voltage to a desired level.

To perform the first two functions, the shunt active filter acts as a controlled current source and its output current should include harmonic, reactive and negative phase sequence components in order to compensate these quantities in the load current. In other words, if the load current of phase "a" is expressed as:

$$\begin{aligned} i_{aL} &= I_{1pm} \cos(\omega t - \theta_1) + I_{aLn} + \sum I_{aLk} \\ &= I_{1pm} \cos\omega t \cos\theta_1 + I_{1pm} \sin\omega t \sin\theta_1 + I_{aLn} + \sum I_{aLk} \end{aligned} \quad (9)$$

It is clear that the current output of the shunt active filter should be:

$$i_{ah} = I_{1pm} \sin\omega t \sin\theta_1 + I_{aLn} + \sum I_{aLk} \quad (10)$$

Hence, the current from the source terminal will be:

$$i_{as} = i_{aL} - i_{ah} = I_{1pm} \cos\omega t \cos\theta_1 \quad (11)$$

This is a perfect, harmonic-free sinusoid and has the same phase angle as the phase "a" voltage at the load terminal. The power factor is unity. It means that the reactive power of load is not provided by the source.

### 3.3 UPQC Control Scheme

It is clear from the above discussion that UPQC should first separate out the fundamental frequency positive sequence from the other components. Then it is necessary to control the outputs of the two active filters in the way shown in equations (8) and (10) in order to improve overall power quality at the load terminal.

To solve the first problem, a synchronous d-q-0 reference frame is used. If the 3-phase voltages are unbalanced and contain harmonics, the transformation to the d-q-0 axes results in

$$\begin{aligned} \begin{bmatrix} V_d \\ V_q \\ V_0 \end{bmatrix} &= \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120^\circ) & \cos(\omega t + 120^\circ) \\ -\sin(\omega t) & -\sin(\omega t - 120^\circ) & -\sin(\omega t + 120^\circ) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \\ &= \Delta \begin{bmatrix} V_{dp} \\ V_{qp} \\ 0 \end{bmatrix} + \begin{bmatrix} V_{dn} \\ V_{qn} \\ 0 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ V_{00} \end{bmatrix} + \begin{bmatrix} V_{dk} \\ V_{qk} \\ 0 \end{bmatrix} \end{aligned} \quad (12)$$

Equation (12) shows that the fundamental positive sequence components of voltages are represented by dc values in the d-q-0 frame. Here,  $\phi_p$  is the phase difference between the positive sequence component and the reference voltage (phase "a"). For the proper functioning of a power supply system, it is desirable that the voltages at the load terminal should be perfect sinusoids with constant amplitude. Even under a voltage disturbance, the load still requires a constant voltage. This means that when transformed to the d-q-0 axis, the load voltage become:

$$\begin{bmatrix} V_{dF}^* \\ V_{qF}^* \\ V_{0F}^* \end{bmatrix} = \sqrt{\frac{3}{2}} \begin{bmatrix} V_m \\ 0 \\ 0 \end{bmatrix} \quad (13)$$

Where,  $V_m$  is the rated or desired voltage at the load terminal. Only one value,  $V_m$ , in the d-axis would be sufficient to represent the balanced, perfect sinusoidal, 3-phase voltages in the abc frame. Therefore  $v_{dp}$  should be maintained at,  $\sqrt{3/2}V_m$  while all the other components should be eliminated by the series active filter.

Similar expression can be obtained for the current

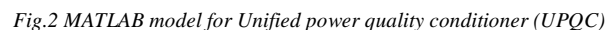
$$\begin{aligned} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} &= \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 120^\circ) & \cos(\omega t + 120^\circ) \\ -\sin(\omega t) & -\sin(\omega t - 120^\circ) & -\sin(\omega t + 120^\circ) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \\ &= \sqrt{\frac{3}{2}} \left\{ \begin{bmatrix} I_{1pm} \cos\theta_1 \\ I_{1pm} \sin\theta_1 \\ 0 \end{bmatrix} + \begin{bmatrix} I_{1nm} \cos(2\omega t + \theta_n) \\ -I_{1nm} \sin(2\omega t + \theta_n) \\ 0 \end{bmatrix} + \begin{bmatrix} \sum I_k \cos(k-1)(\omega t + \theta_k) \\ \sum I_k \sin(k-1)(\omega t + \theta_k) \\ 0 \end{bmatrix} \right\} \end{aligned} \quad (14)$$

Unlike load voltage, load current can change according to the connected loads. Therefore, it is not possible to assign it's reference value. Instead, a new "moving time window" method is applied here to capture the active quantity of the fundamental positive sequence component which is expressed as a dc value in the d-axis. Furthermore, from equation (14), it is evident that the average of the other components, apart from  $I_{1pm} \cos\theta_1$ , in the d-axis is zero in one fundamental cycle period because all of them are harmonics of the fundamental. Therefore a time window with a width of 0.02 seconds (for 50 Hz system) maybe selected to calculate the dc value. The

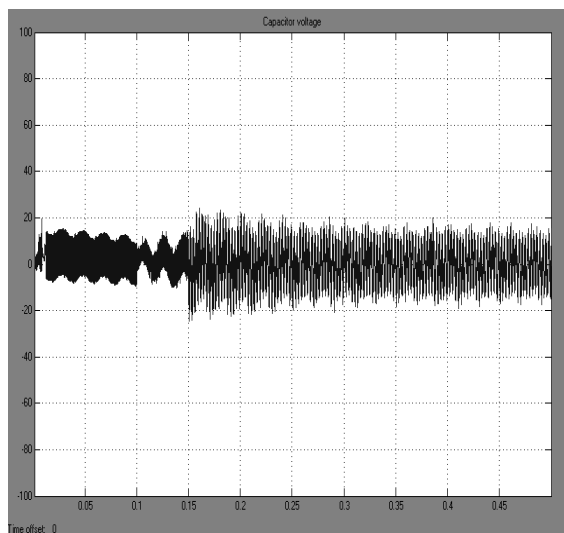
forward. If the moving frequency is also 50 Hz, the delay caused by the calculation is 0.02s. However if the moving frequency is  $n$  times of 50 Hz, the delay will be  $0.02/n$  seconds. As the window moving frequency increases, calculation delay becomes shorter but the frequency at which the data moving into and out of the window is higher. Fortunately, in practical power systems, load current changes slowly. The two voltage-source inverters (VSIs) are used as the series and shunt active filters. The series active filter should behave as a controlled voltage source and its output voltage should follow the pattern of voltage given in equation (8). This compensating voltage signal can be obtained by comparing the actual load terminal voltage with the desired value  $v_F^*$ . Since the desired  $v_F^*$  is already defined, it is easy to calculate  $v_h (= v_F^* - v_s)$  as  $v_s$  is a known quantity. After obtaining the voltage signal  $v_h$ , the switching duty ratio of the series active filter is obtained by giving this signal to the hysteresis controller. The shunt active filter acts as a controlled current source. It means that the inverter operates in the current-regulated modulation mode[3]-[6]-[14].

In this section the simulation analysis of UPQC is described for R-L load and the FFT analysis has been carried out simultaneously. In this two filters are used i.e. shunt active power filter and series active power filter. The shunt active power filter compensates for the source current harmonics and also it maintains the dc link voltage unchanged in steady state, while the series active power filter compensates for the load voltage harmonics.

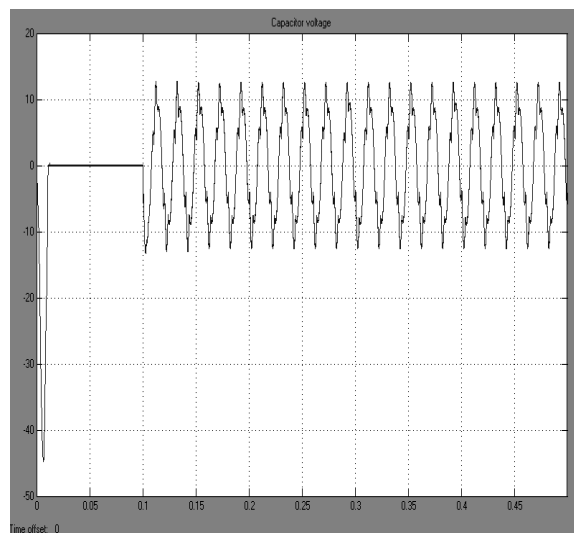
The operation of the simulation model shown below is described as – first the reference voltages and the reference currents are generated and then the reference voltages are compared with the actual load voltages and the reference currents are compared with the actual source currents and then the error signals are given to the hysteresis controllers for generating the switching signals for the switches of series active power filter and the shunt active power filter. And the generated pulses are then given to the series and shunt APF's and accordingly the switches are turned on and off to compensate for the voltage and current harmonics.



IJSER © 2012  
<http://www.ijser.org>



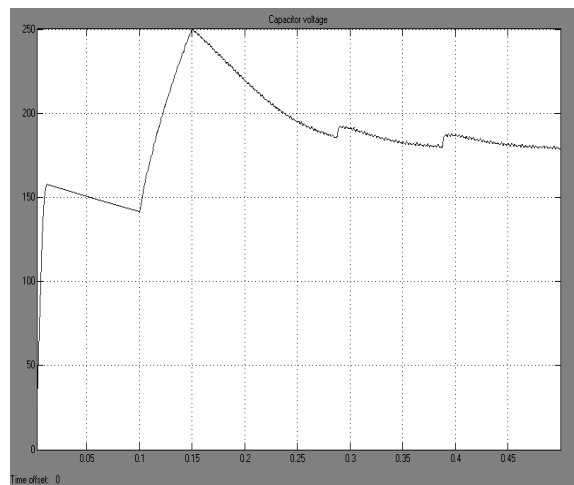
*Fig.4 Compensating voltage for phase 'A'*



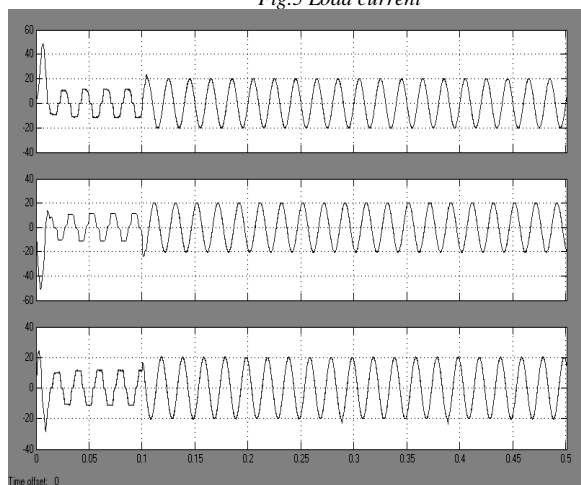
*Fig.7 Compensating current for phase 'A'*



*Fig.5 Load current*



*Fig.8 Capacitor voltage*



*Fig.6 Source current before and after compensation*

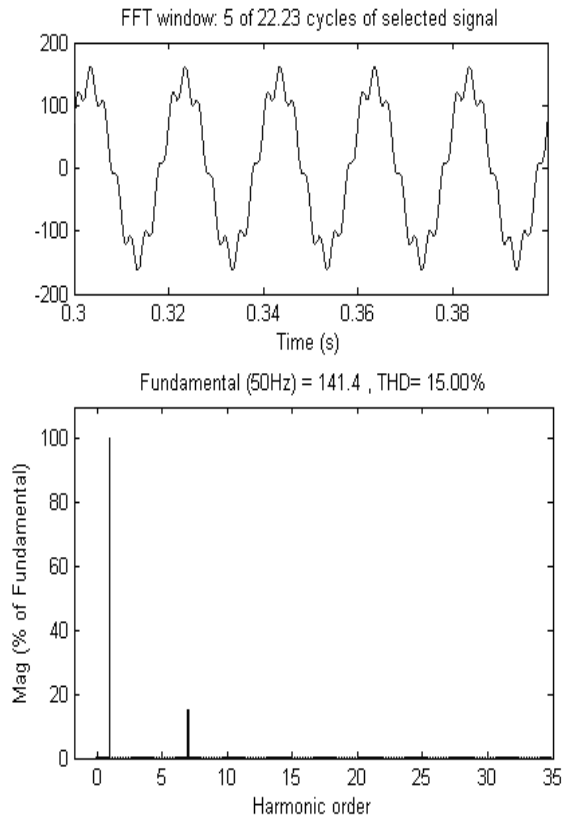


Fig.9 FFT analysis for source voltage

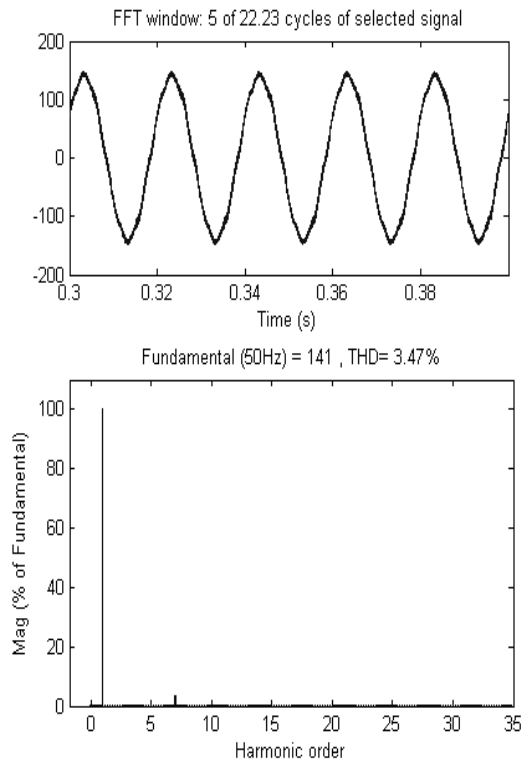


Fig.10 FFT analysis for load voltage

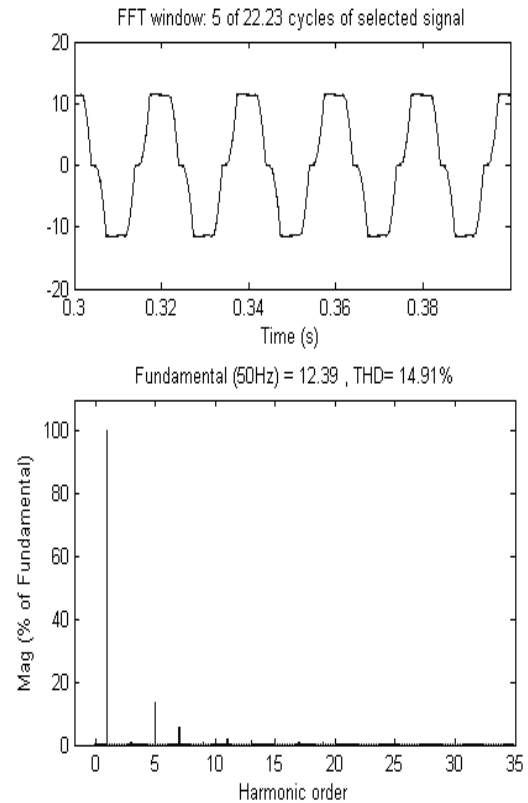


Fig.11 FFT analysis for load current

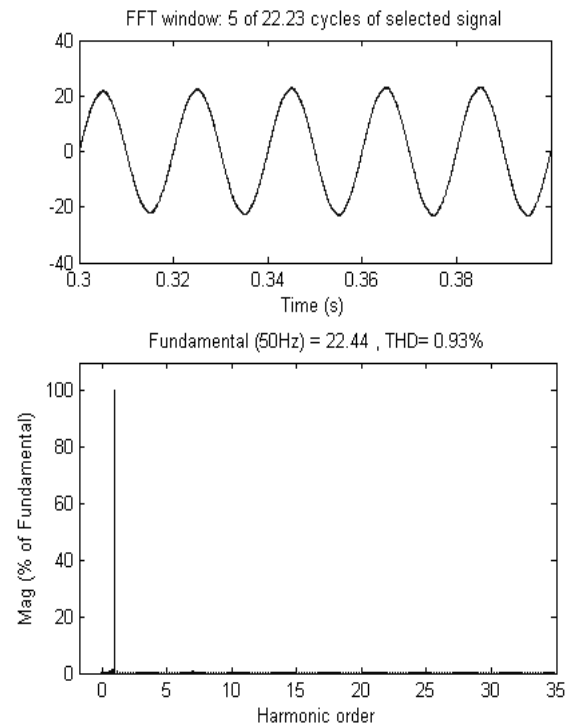


Fig.12 FFT analysis for source current



#### 4.2.1 Result

Load Type	THD (%) Load Current	THD (%) Source Current
R – L Load	14.91	0.93

Table 1 THD analysis of Load and Source Current for R-L Load of UPQC

The table1 shows that the THD analysis for the load current and the source current. It is clear from the table that the performance of the system improves and the THD is reduced up to very large extent.

Load Type	THD (%) Source Voltage	THD (%) Load Voltage
R – L Load	15	3.47

Table 2 THD analysis of Source and Load Voltage for R-L Load of UPQC

The table2 shows that the THD analysis for the source voltage and the load voltage. It is clear from the table that the performance of the system improves and the THD is reduced up to very large extent.

#### 5 CONCLUSION

A MATLAB based model for the UPQC has been simulated for R-L load using hysteresis control technique. The simulation results show that the input voltage harmonics and the current harmonics caused by non-linear load are compensated very effectively by using the UPQC.

#### REFERENCES

- [1] Bhim Singh, Kamal Al Haddad and Ambrish Chandra, A Review of Active Filters for Power Quality Improvement, IEEE Trans on Industrial Electronics, Vol.46, No.5, October 1999, pp. 960-970..
- [2] E.E.EL-Khoy, A. EL-Sabbe, A.El-Hefnawy, and Hamdy M.Mharous, Three phase active power filter based on current controlled voltage source inverter, Electrical Power and Energy Systems, 28 (2006), 537-547.
- [3] G. Carrara, S. Gardelta, M. Marchesoni, A new multilevel PWM method: theoretical analysis, IEEE Trans. On power electronics Vol. 7. No. 3, July, pp.497-505, 1992.
- [4] V. Khadkikar, P. Agarwal, A. Chandra, A.O. Barry and T.D. Nguyen; "A Simple New Control Technique For Unified Power Quality Conditioner (UPQC)"; 11th International Conference on Harmonics and Quality of Power-2004, pages: 289-293.
- [5] M Vilathgamuwa, Y H Zhang., and S.S.Choi; "Modeling, Analysis and Control of Unified Power Quality Conditioner"; 8<sup>th</sup> International Conference on Harmonics and Quality of Power ICHQP '98, by IEEE/PES and NTUA, October 14-16, 1998, pages: 1035-1040.
- [6] Hideaki Fujita, Member, IEEE and Hirofumi Akagi, Fellow, IEEE, "The Unified Power Quality Conditioner: The Integration of Series and Shunt

- Active Filters", IEEE Transaction on power electronics. Vol.13. No 2 march 1998, pages: 494-501
- [7] M. Kazmierkowski, L.Malesani, Current Control Techniques for Three Phase Voltage Source PWM converters: A survey, IEEE Trans on Industrial Electronics, vol.45, no.5, pp.691- 703, October 1998.
- [8] M.H. Rashid, Power Electronics, Circuits, Devices, and Applications 2nd ed., Prentice Hall 1993 "An exploration of the state-of- the-art in power conversion techniques and power semiconductor devices."
- [9] Roger C.Dugan, Mark F. McGranaghan, Surya Santo so and H.Wayne Beaty, Electrical Power System Quality, McGraw –Hill.
- [10] S. Buso, L. Malesani, P. Mattavelli, Comparison of current control Techniques for Active power Filter Applications, IEEE Transactions on Industrial Electronics, Vol.45, no.5, pp.722-729, Oct 1998..
- [11] Yunping Chen, Xiaoming Zha\*Jin Wang, Huijin Liu, Jianjun Sun and Honghai Tang "Unified Power Quality Conditioner (UPQC): The Theory, Modeling and Application" an IEEE paper-2000.
- [12] V. Agelidis, M. Calais, Application specific harmonic performance evaluation of multicarrier PWM techniques, IEEEESC' 98 Conference Record, pp. 172-178, 1998.
- [13] Y.Sato, T.Kawase, M.Akiyama, and T.Kataoka, A control strategy for general – purpose active filters based on voltage detection, IEEE Trans. Ind. Appl., vol. 36, no.5, pp.1405–1412, Sep / Oct.2000
- [14] Donghua Chen; Shaojun Xie; "Review of the control strategies applied to active power filters"; Electric Utility Deregulation, Restructuring and Power Technologies, 2004. (DRPT 2004). Proceedings of the 2004 IEEE International Conference on, Volume 2, 5-8 April 2004 Page(s):666 - 670 Vol.2
- [15] Jain, S.K.; Agarwal, P.; Gupta, H.O.; "A control algorithm for compensation of customer-generated harmonics and reactive power"; Power Delivery, IEEE Transactions on, Volume: 19, Issue: 1, Jan. 2004 Pages: 357 – 366.

#### APPENDIX

The values of different parameters used for UPQC have been given below.

- Source voltage: 3-phase, 100V, 50Hz.
- Harmonics in the supply voltage: 5<sup>th</sup>, 0.2pu and 7<sup>th</sup>, 0.15pu.
- Proportional gain  $K_p$ : 0.5 and Integral gain  $K_i$ :10
- Capacitor reference voltage: 300V
- Series transformer rating: 1kVA, 50Hz, 240/240V
- RL load parameters :10  $\Omega$ , 100mH
- Line parameters : 0.2  $\Omega$ , 1.5mH
- RC filter parameters : 16  $\Omega$ , 199.04 $\mu$ F
- Hysteresis band gap : -0.01 to 0.01