Available online at www.sciencedirect.com

ScienceDirect

Materials Today: Proceedings 5 (2018) 965–972

materialstoday: PROCEEDINGS

www.materialstoday.com/proceedings

PMME 2016

# UPQC: A Custom Power Device for Power Quality Improvement*

Gowtham N[a], Dr.Shobha Shankar[b]*

[a]*Research Scholar, Dept.of EEE, Vidyavardhaka College of Engineering, Mysuru-570 002, India*
[b]*Professor and Head, Dept.of EEE, Vidyavardhaka College of Engineering, Mysuru-570 002, India*

**Abstract**

Power Quality (PQ) has increased concern amongst utilities at all levels of usage. The development of power electronic devices has made a notable impact on the quality of electric power supply. The operation of nonlinear loads generates harmonics and thus, deteriorates the quality of distribution system. In such cases both utilities and end users of electric power are gradually more concerned about the quality of power. This suggests that few course of action has to be taken so that the power quality can be improved. In this paper the main focus is on UPQC, which is a combination of series and shunt active power filters. The series APF alleviates voltage based distortions, while shunt APF mitigates current based distortions. UPQC alleviates the voltage and current based distortions concurrently as well as independently. UPQC improves power quality by compensating both harmonics and load current which thereby makes source current and load voltage sinusoidal at the required voltage level.The modelling of series APF, shunt APF and the UPQC has been carried out using MATLAB/Simulink.


Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

*Keywords:*Power Quality; Unified Power Quality Conditioner; Active Power Filter;Voltage Source Inverter; Total Harmonic Distortion.


* Corresponding author. Tel.: 9741402856.
*E-mail address:*gowtham.n@vvce.ac.in; shobha.shankar@vvce.ac.in.


Selection and Peer-review under responsibility of International Conference on Processing of Materials, Minerals and Energy (July 29th – 30th) 2016, Ongole, Andhra Pradesh, India.

## 1. Introduction

Today power quality has become the most vital factor for both suppliers and customers due to the deregulation of the electric power energy market. Efforts are being made to improve the power quality. Power electronic valves are the basis of those custom power devices such as the state transfer switch (STS), active filters and converter based devices (Awad et al., 2003). The active filter technology is now mature for providing compensation for harmonics, reactive power, and/or neutral current in ac networks. Active Filters are also used to eliminate voltage harmonics, control terminal voltage, reduce voltage flicker, and improve voltage balance in three-phase systems (Bhim Singh et al.,1999).The reactive power control theory for three-phase systems with or without neutral wire, is valid for both steady state and transients(Akagi et al., 1983).

A SPLL model uses a lag or lead loop controllerin order to analyse the system performance and filtering characteristics, these characteristics are analysed by the use of bode diagrams and root-locus methods. The practical aspect of the SPLL (S. R. Naidu et al., 2004)implementation has also been discussed. The operating principle and design considerations of a SPLL under practical conditions are voltage unbalance, voltage harmonics, frequency change, phase jumps and sampling delay.A series active power filter working as a sinusoidal current source, is considered in phase with the mains voltage. The amplitude of the fundamental current in the series filter is controlled with the help of error signal generated between the load voltage and a pre-established reference. The control provides the effective correction of power factor, harmonic distortion, and load voltage regulation (Juan W. Dixon et al., 1997).DVR principles and voltage restoration methods at the point of common coupling (PCC) were analysed with different voltage injection methods(ChellaliBenachaiba et al., 2008).Dynamic voltage controller with hysteresis controller was analysed using discrete Fourier transform (DFT) scheme for sag and swell detection.(F.A.L Jowder et al., 2007).

A control algorithm for the dynamic voltage restorer (DVR) is used to mitigate the power quality problems in terminal voltage. Two PI (proportionalintegral) controllers are used each to regulate the dc bus voltage of DVR and the load terminal voltage respectively(Bhim Singh et al., 2011). The fundamental component of the terminal voltage is derived using the synchronous reference frame theory. A three-phase Series Active Power Filter is modelled as Power Quality Conditioner using a simplified control algorithm. Series APF compensates supply voltage unbalance and harmonics in such a way that they do not reach the load end resulting in low THD at the load voltage (M. A. Chaudhari et al., 2012).

The instantaneous reactive power theory, also known as p–q theory based on a new control algorithm is analysed for 3-phase 4-wire(Mehmet Ucar et al., 2008) and 4-leg shunt active power filter (APF) to suppress harmonic currents, compensate reactive power, neutral line currents and balance the load currents under unbalanced non-linear load and non-ideal mains voltage conditions.

Unified Power Quality Conditioner (UPQC),is an amalgamation of series APF and shunt APF. A control strategy based on unit vector template is explained in this paper with the focus on the mitigation of voltage harmonics present in the utility voltage(V.Khadkikar et al., 2006). The steady state analysis of unified power quality conditioner (UPQC) was performed. The mathematical analysis is based on active and reactive power flow through the shunt and series APF, wherein series APF can absorb or generate the active power whereas the reactive power requirement is totally handled by shunt APF.

The UPQC (Yash Pal et al., 2011) is realized by integration of series and shunt active power filters (APFs) sharing a common dc bus capacitor. The shunt APF is realized using a three-phase, four leg voltage source inverter (VSI) and the series APF is realized using a three-phase, three legs VSI.

## 2. Unified Power Quality Conditioner(UPQC)

Unified Power Quality Conditioner (UPQC) is a multitasking power conditioner that can be used to compensate many voltage disturbancesof the power supply, voltage fluctuations, and to prevent harmonic load current from entering the power system. It is a custom power device designed to alleviate the disturbances that affect the performance of sensitive loads. UPQC consists of two voltage-source inverters with a common dc link designed in single-phase, three-phase three-wire, or threephase four-wire configurations [2]. One inverter is regulated as a variable voltage source in the series active power filter (APF), another inverter is controlled as a variable current source in the shunt active power filter (APF). The series Active Filter compensates for voltage supply disturbances (e.g., including harmonics, imbalances,sag, swell, flickers, negative and zero sequence components). The shunt filtercompensates for load current distortions (e.g., caused by harmonics, imbalances), reactive power and performs the dc link voltage regulation.

### *2.1. Components of UPQC*

The key components of UPQC include, Series inverter (voltage-source inverter) connected in series with AC line through a series transformer and acts as a voltage source to mitigate voltage distortions. UPQC eliminates supply voltage flickers and imbalances from the load terminal voltage. Control of the series inverter output is performed by using pulse width modulation (PWM). Among the various PWM technique, the hysteresis band PWM is frequently used because of its ease of implementation. Also, besides fast response, the method does not need any knowledge of system parameters. The details of the hysteresis control technique are analysed in the subsequent sections. Shunt inverter: It is a voltage-source inverter connected in shunt with the same AC line which acts to cancel current distortions, compensate reactive current of the load and improve the power factor of the system. It also performs the DC-link voltage regulation, resulting in a significant reduction of the DC capacitor rating. The output current of shunt converter is adjusted using a dynamic hysteresis band by controlling the status of the semiconductor switches such that output current follows the reference signal and remains in a predetermined hysteresis band.

DC link capacitor: The two VSIs are connected back to back with each other through this capacitor. The voltage across this capacitor provides the self-supporting DC voltage for proper operation of both the inverters.

Low-pass filter is used to attenuate high-frequency components of the voltages at the output of the series converter that are generated by high-frequency switching of VSI.High-pass filter is installed at the output of shunt converter to absorb ripples produced due to current switching[4].

Series transformer: The necessary voltage generated by the series inverter to maintain a pure sinusoidal load voltage and at the desired value is injected in to the line through these series transformers.

### *2.2. Modeling of UPQC*

Unified power quality conditioning is the matter of conditioning the components of the power i.e. Supply voltage and Load current. Figure 1 shows the Simulink model of UPQC. Table I is utilized for modelling of the test system.

The conditions to satisfy conditioning or modelling are as follows:

- If any fluctuation or harmonics occurs in the supply voltage, it should not be affected to the load. So, we need to take care of the voltage to be sinusoidal and controlled at desired value.
- If there is a non-linear load at the load side, then it consumes non-linear current which leads to non-linearity in the grid part and that affects to other loads also. So, we need to take care of the current to be sinusoidal and to make it like there should have minimum amount of THD value.
- Reactive power to be maintained at zero level at Grid point.

Table 1.Simulation parameters.

| Parameters | Values |
|---|---|
| Supply Voltage | 230V, 50Hz |
| Grid parameters | R =0..02Ω, L= 1µH |
| Converter parameters | 5mH |
| Load | R = 40Ω |

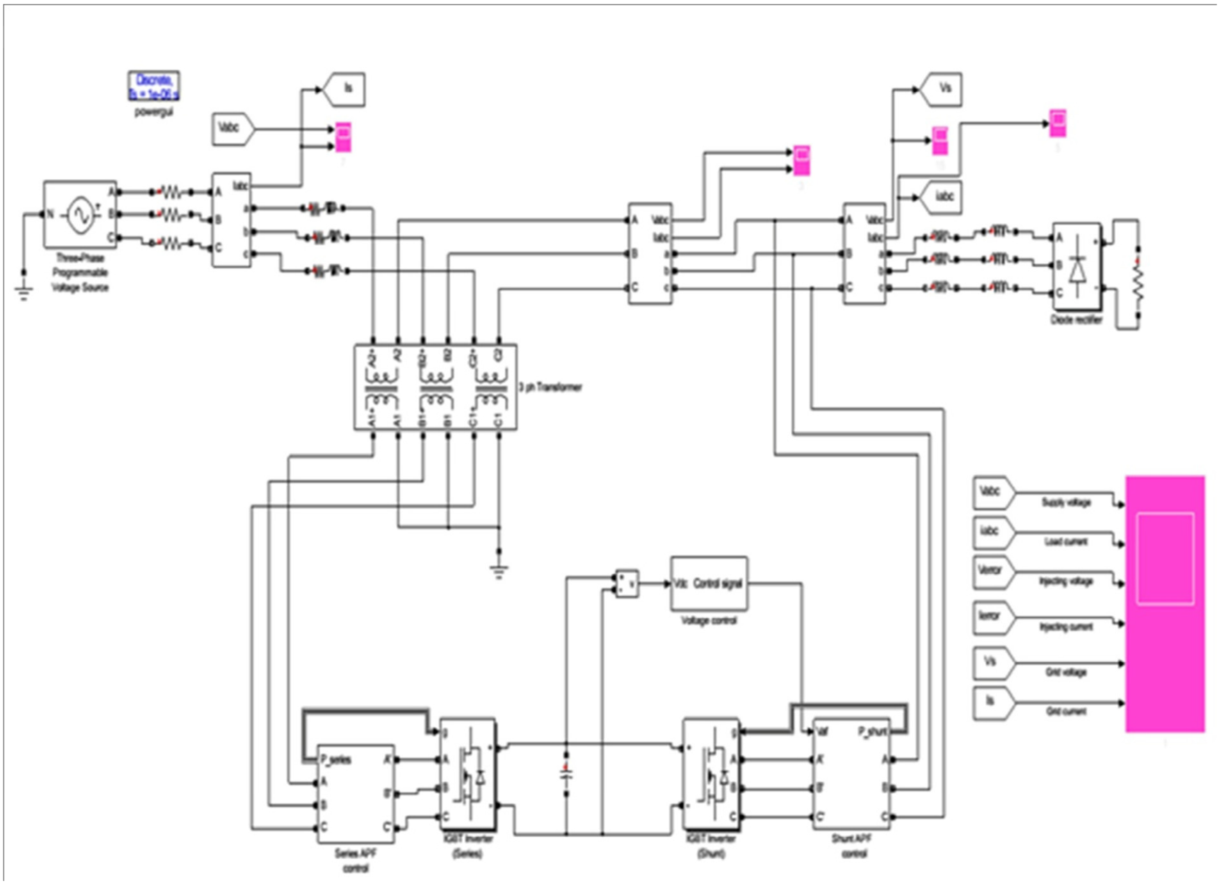


Fig.1 Simulink model of UPQC

## 3. Results and Discussions

The UPQC part includes 3 points-

- Voltage compensation(Series APF)

Series Active power filter (APF) is helpful in compensating the voltage, i.e it will calculate the voltage error that is present in the grid and how much voltage has to induced in the grid to make the voltage sinusoidal with the desired voltage magnitude and frequency.The supply voltage hasto be subtracted by reference voltage(Vabc*), it calculates the error in voltage which is then compared with error voltage produced in the lines and then will proceed to PWM control to produce the pulses to minimize the error produced by the difference in calculated error voltage and produced error voltage.

- Current Compensation(Shunt APF)

Current compensation will decide how much current error is present in the grid and how much current has to induced in the grid to make the current sinusoidal with desired current magnitude and frequency.The load current has to be subtracted by reference currents (Iabc*) which will be sinusoidal where Id and Iq currents are purified by collecting load currents, it will calculate the error in current which is then compared with error current produced in 3 lines and then will proceed to PWM control to produce the pulses to minimize that error produced by the difference in calculated error current and produced error current.

- DC capacitor voltage controller

The DC capacitor voltage has to be maintained at some desired value. The reference value has to be subtracted by measured DC voltage and the error has to be minimized to zero by a transfer function and the control signal has to be added to Id current.

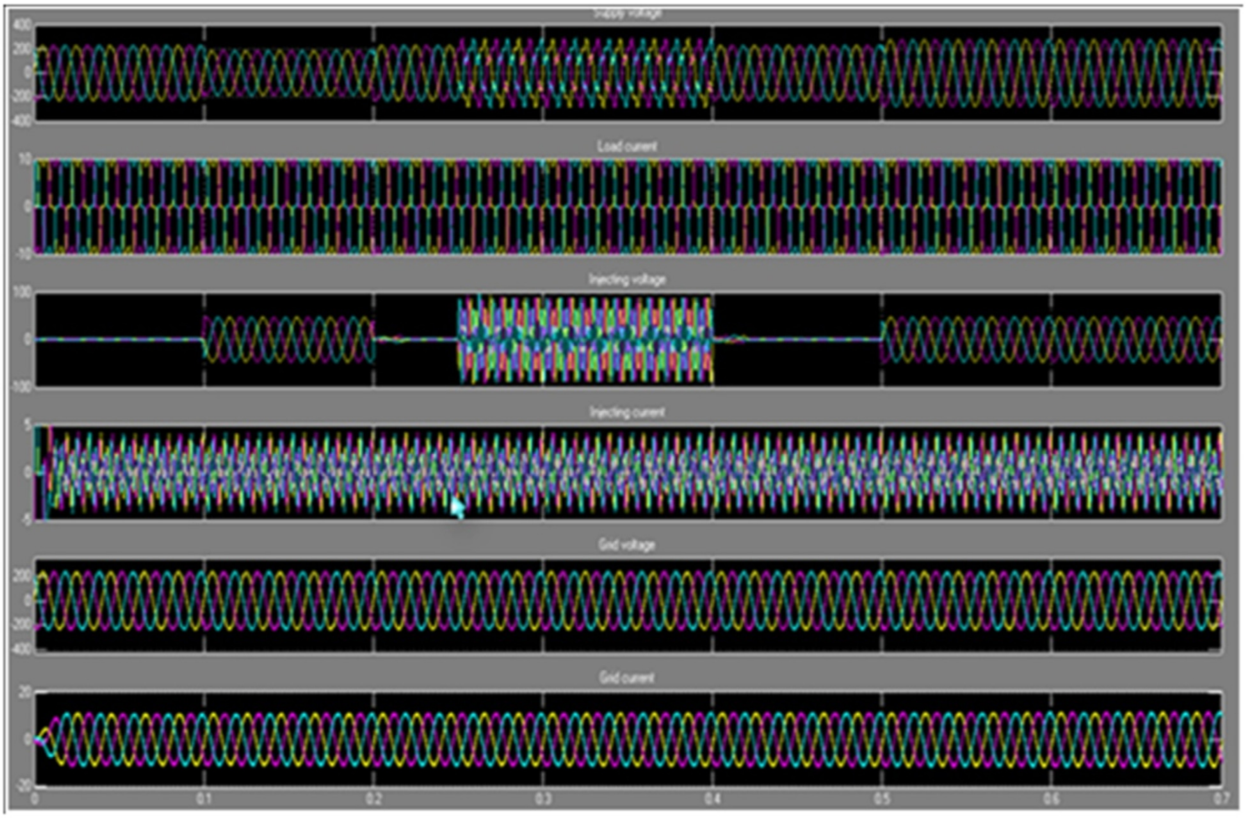

Fig.2 Supply voltage and load current before and after compensation

Figure 2, shows the effect of series and shunt active power filter in compensating voltage and current, the supply voltage is non-sinusoidal and the load current is nonlinear. As series active power filter is used it will calculate the error that is present and injects the required amount of voltage to it sinusoidal. Similarly the shunt active power filter calculates the error that is present and injects the reference currents to make the current sinusoidal with desired magnitude and frequency.

*3.1 Total Harmonic Distortion(THD)*

To validate the performance of UPQC, simulations are performed by modeling the test system with MATLAB/Simulink. Total Harmonic Distortion is evaluated to verify the performance ofdesigned control methods. Fig.3 and Fig 4 shows supply voltage during harmonic conditions before and after compensation, the series active power filter is responsible in compensating the harmonics. Also shunt active power filter is responsible in alleviating current harmonics, fig 5 and fig 6 depicts the harmonic spectrum of current harmonics before and aftercompensation,and the percentage THD is below the harmonic limit imposed by IEEE 519-1992.

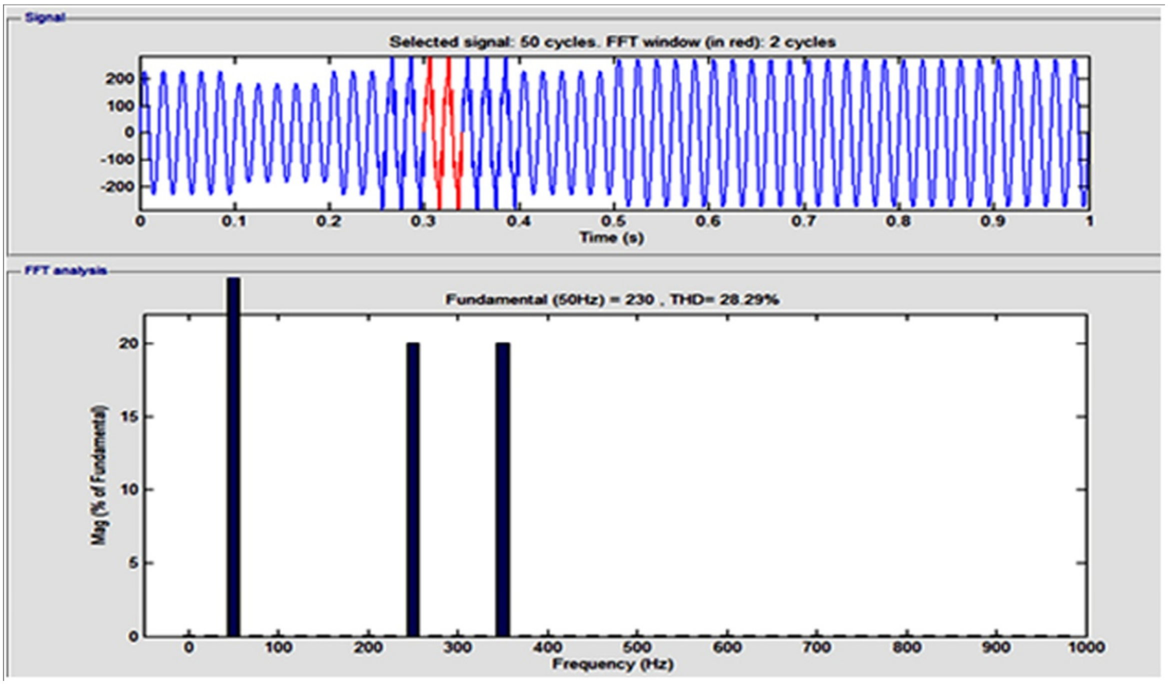


Fig.3.Harmonic spectrum of supply voltage before compensation

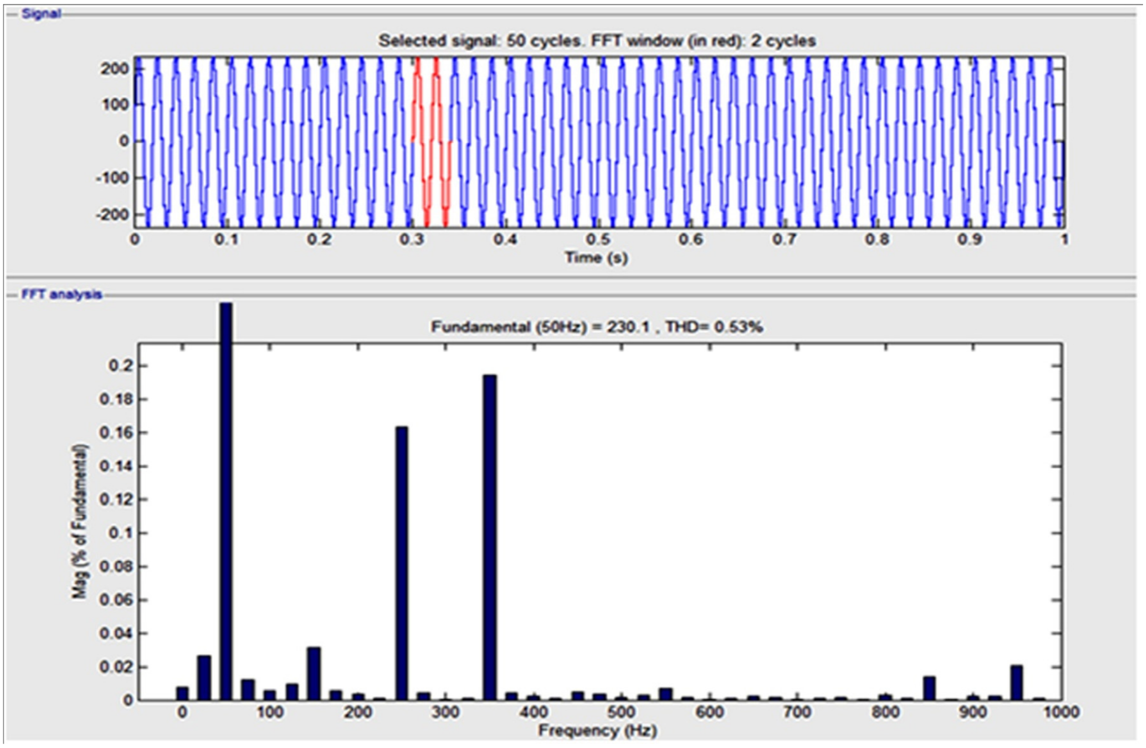


Fig.4.Harmonic spectrum of supply voltage after compensation

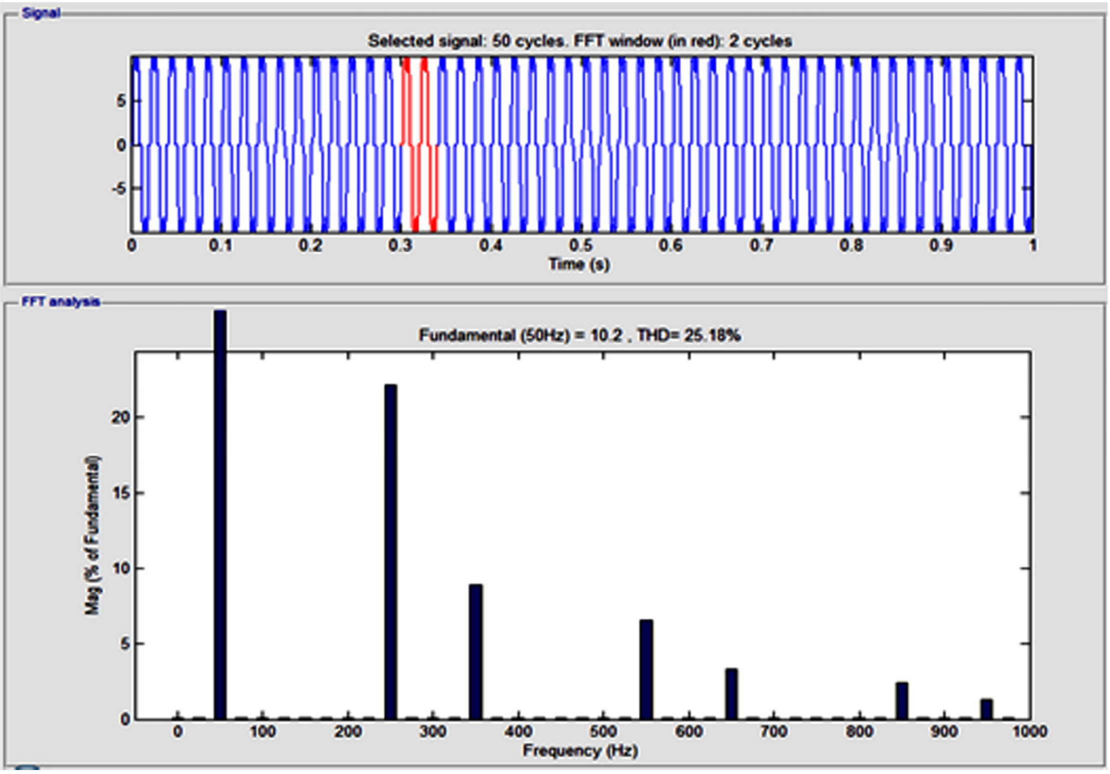


Fig.5.Harmonic spectrum of grid currentbefore compensation

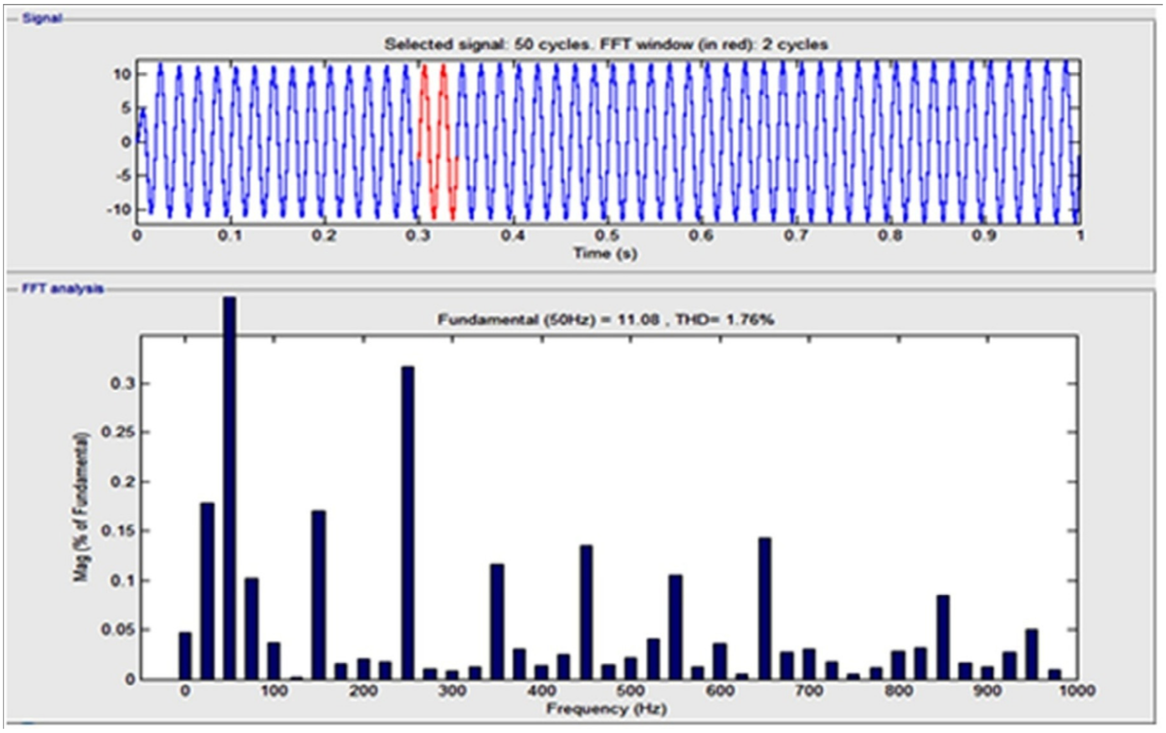


Fig.6.Harmonic spectrum of grid current after compensation

## 4. Conclusion

This paper discusses an implementation of series and shunt active power filters as UPQC to compensate for voltage distortions and for alleviating current harmonics. The source voltage THD after compensation is well within the IEEE 519 recommended standard. The modelling of series APF, shunt APF and the UPQC has been carried out. A simple control technique, extraction of unit vector template has been used to model the control scheme for series APF. This scheme utilizes phase locked loop (PLL) and a hysteresis band controller to generate the reference signals for series APF. The instantaneous reactive power theory has been used to model the control scheme for shunt APF.
It is found from the simulation results that UPQC improves power quality of power system by compensating harmonic and reactive current of load current which makes source current sinusoidal and it also makes load voltage sinusoidal at required voltage level by compensating with series APF. The THD of the source current and load voltage is below the harmonics limit imposed by IEEE standard 519-1992.

## References

[1] H. Awad, M. H.J Bollen, "Power Electronics for Power Quality Improvements," IEEE Symposium on Industrial Electronics, vol.2 , pp.1129-1136, 2003.
[2] 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, oct.1999, pp.960-971.
[3] H. Akagi, Y. Kanazawa, A. Nabae , "Generalized Theory of the Instantaneous Reactive Power in Three Phase Circuits", in Proc. IPEC-Tokyo'83 Int. Conf. Power Electronics, Tokyo, pp. 1375-1386.
[4] S. R. Naidu, A. W. Mascarenhas and D. A. Fernandes "A Software Phase-Locked Loop for Unbalanced and Distorted Utility Conditions," IEEE POWERCON Nov.2004,vol. 2, pp. 1055-1060.
[5] Juan W. Dixon, Gustavo Venegas and Luis A. Moran, "A Series Active Power Filter Based on a Sinusoidal Current-Controlled Voltage-Source Inverter" IEEE Transactions on Industrial Electronics, Vol. 44, Issue: 5, Page(s): 612 - 620, Oct. 1997.
[6] ChellaliBenachaiba, BrahimFerdi ,"Voltage Quality Improvement Using DVR",Electrical Power Quality and Utilisation, Journal Vol. XIV, No. 1, 2008, pp.30-46.
[7] F. A. Jowder, "Modeling and Simulation of Dynamic Voltage Restorer (DVR) Based on Hysteresis Voltage Control," The 33rd Annual Conference of the IEEE Industrial Electronics Society (IECON) Nov. 2007, pp. 1726-1731.
[8] F.A.L. Jowder , "Design and Analysis of dynamic voltage restorer for deep voltage sag and harmonic compensation" ,IET Generation, Transmission & Distribution,2009, Vol.3,Iss. 6, pp. 547-560.
[9] Tarek I. El-Shennawy, Abdel-Mon'emMoussa, Mahmoud A. El-Gammal and Amr Y. Abou-Ghazala, "A Dynamic Voltage Restorer for Voltage Sag Mitigation in a Refinery with Induction Motors Loads" American J. of Engineering and Applied Sciences 3 (1):144-151, 2010
[10] B. Singh, P. Jayaprakash, D. P. Kothari, A. Chandra and Kamal-Al-Haddad , " New Control Algorithm for Capacitor Supported Dynamic Voltage Restorer" Journal of Electromagnetic Analysis and Applications, 2011, 3, 277-286 .
[11] M. A. Chaudhari and Chandraprakash, "Three-Phase Series Active Power Filter as Power Quality Conditioner," IEEE International Conference on Power Electronics, Drives and Energy Systems, Dec. 2012, pp. 1-6.
[12] Mehmet Ucar and EnginOzdemir, "Control of a 3-phase 4-leg active power filter under non-ideal mains voltage condition", Electric Power Systems Research 78 (2008) 58–73.
[13] V. Khadkikar, P. Agarwal, A. Chandra, A.O. Bany and T.D.Nguyen , "A Simple New Control Technique For Unified Power Quality Conditioner (UPQC)," IEEE International Conference on Harmonics and Quality of Power, Sept. 2004, pp. 289 – 293.
[14] Yash Pal, A. Swarup, Bhim Singh, "A control strategy based on UTT and of three-phase, fourwire UPQC for power quality improvement " International Journalof Engineering, Science and Technology Vol. 3, No. 1, 2011, pp. 30-40.