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Harmonic Reduction in Power Distribution Network using UPQC

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Abstract : *Unified Power Quality Conditioner (UPQC) is a versatile custom power device. It consists of two VSCs connected back-to-back to compensate for both distorted Point at Common Coupling (PCC) voltage and supply current imperfections. UPQC is designed to prevent the harmonics injected by the non-linear load from entering the source terminal. Regulation of voltage at the point of common coupling is carried out by series connected converter. SRF based current control method is used for current compensation by the shunt device. Hysteresis voltage control technique is used for shunt compensation by the series device which simultaneously acts as shunt and series active power filters. Maintaining a constant value for dc link voltage is essential for UPQC to perform normally which is carried out by shunt connected VSC. MATLAB based simulation is carried out to demonstrate the effectiveness of the proposed control scheme.*

Keywords : *UPQC, Non-Liner RL Load, Harmonics, synchronous reference frame (SRF), Hysteresis Voltage, Control Point at Common Coupling (PCC).*

I. INTRODUCTION

Use of non–linear and time varying loads has led to distortion of voltage and current waveforms and increased reactive power demand in AC mains. Distortion due to harmonics is known to be the source of several problems, such as increased power losses, excess heating in rotating machinery, flicker and audible noise, significant interference with communication circuits, and incorrect operation of sensitive loads[1].Power electronics based equipment which includes adjustable–speed motor drives, DC motor drives, electronic power supplies, electronic ballasts, battery chargers are responsible for the rise in power quality related problems. Power quality is affected by harmonic distortion, temporary interruptions, voltage sag, voltage swell, under voltages, voltage spikes and noise [2]. Non-linear loads appear to be prime sources of harmonic distortion in a power distribution system. As the harmonic currents pass through the line impedance of the system, harmonic voltages appear, causing distortion at the coupling point. Harmonics have a number of undesirable effects on the distribution system. There are two basic categories: short term and long term. Short–term effects are usually the most noticeable and are related to excessive voltage distortion. Long–term effects often go undetected and are usually related to increased resistive losses or voltage stress [3]. In addition, harmonic currents produced by nonlinear loads can interact adversely with a wide range of power system equipment, most notably capacitors, transformers and motors, causing additional losses, overheating and overloading. As the presence of harmonics in distribution system is harmful, there is a need to define a framework to suppress it. To mitigate these identified power quality problems efforts are going on in the field of filters. Present day power quality renders these efforts futile. New technology known as custom power devices(CPD) has been developed for such distribution systems. These devices are applicable to distribution systems for enhancing the reliability and quality of the power supply. CPDs include DSTATCOM, DVR[6] and UPQC.

The Unified Power Quality Conditioner (UPQC) (figure 1) is one of the versatile custom power device, which can compensate both current and voltage related problems, simultaneously. The series Active Power Filter (APF) compensates voltage-based distortions, while the shunt APF cancels current-based distortions such as harmonics, reactive power and negative sequence current etc.

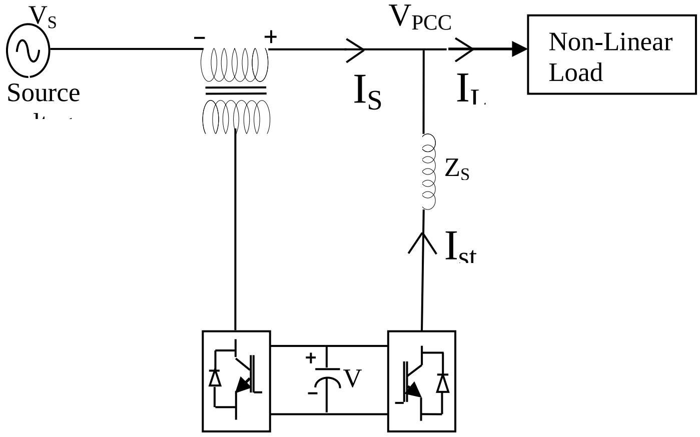

Fig.1. UPQC Block Diagram

The investigator has gone through a number of literatures in this regard. Some of them are:(a) the indirect current control approach, in terms of its simplicity and effectiveness, for the operation of a series APF[4].(b)Simulation of instantaneous active and reactive theory based shunt active filter with MATLAB/ Simulink, a better solution for reduction of the harmonics[5].(c)A series active harmonic compensator which compensates the harmonic contents present in load voltage at PCC[7].

In this paper UPQC is designed to remove the harmonic injected by the non-linear load from entering into the source terminal. Regulation of voltage at the point of common is carried out by series connected converter. SRF based current control method is used for current compensation by the shunt device and Hysteresis voltage control technique is used for series device which simultaneously act as shunt and series active power filters.

II. SYSTEM DESCRIPTION

The system under consideration is shown in Fig.2.The UPQC is connected before the load to protect a sensitive load from any voltage based distortions and simultaneously making the source currents sinusoidal. The UPQC is realized by using two voltage source inverters (VSIs) connected back to back with a common DC link Voltage. One VSI is acting as a shunt APF, while the other as series APF. The series APF[8] is connected between the source and the load with the help of three single phase injection transformer. Injection transformer is used to inject voltage in the line by the series APF. While, shunt APF is connected at point of common coupling (PCC). Each APF is realized by using six Insulated Gate Bipolar Transistors (IGBT) switches[10]. The load under consideration is a non-linear load. A three-phase diode bridge rectifier with a RL load is considered as a non-linear load. The values of the circuit parameters and load under consideration are given in Appendix.

III. CONTROL SCHEME

The series active filters control has been carried out by means of following compensation strategy-

Control strategy which measures the load voltage to make that the APF generates a voltage with that same harmonic content and the opposite sign [9].

$$V_{ch} = K_v \cdot V_{lh} \tag{1}$$

The measurement of the load voltage harmonic generally depends on the instrumentation sensibility k_v. The voltage supplied by the APF is expressed as follows:

$$V_{ch} = K_v \cdot V_{lh} \tag{2}$$

From equation 2, the voltage in the point of common coupling is, for a specific harmonic :

$$V_{cch} = V_{lh}\left(1 - K_v\right) \tag{3}$$

REFERENCE SIGNAL GENERATION

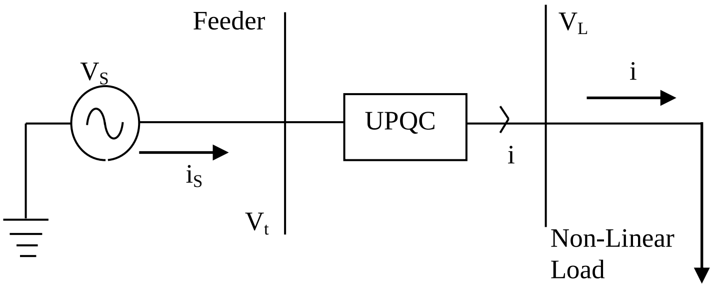

Fig.2 System Under Consideration

The Reference signal generation is done by using UTT theory[11]. The equations showing the generation of the reference signals are given below-

A. Series Active filter

The extraction of three-phase voltage reference signal for series APF is based on Unit Vector Template Generation, achieved with the help of PLL. These Unit Vector Templates are multiplied with the desirable peak amplitude (V_{tmn}) of load voltage to obtained reference load voltages denoted by V_{lar}, V_{lbr} and V_{lcr} for phase a, b and c respectively and are given by-

$$V'_{lar} = V_{tmn} \cdot u_a \tag{4}$$

$$V'_{lbr} = V_{tmn} \cdot u_b \tag{5}$$

$$V'_{lcr} = V_{tmn} \cdot u_c \tag{6}$$

where u_a, u_b and u_c are unit vector templates which are in phase with supply voltage and are given by-

$$u_a = sin(\omega t) \tag{7}$$

$$u_b = sin(\omega t + 120) \tag{8}$$

$$u_c = sin(\omega t - 120) \tag{9}$$

B. Shunt Active Filter

Unit vector template generation theory is again used here. These Unit Vector Templates are multiplied with the desirable peak amplitude I_{tmn} to obtain the reference currents denoted by I_{lar}, I_{lbr} and I_{lcr} for phase a, b and c respectively and are given by-

$$I'_{lar} = I_{tmn} \cdot i_a \tag{10}$$

$$I'_{lbr} = I_{tmn} \cdot i_b \tag{11}$$

$$I'_{lcr} = I_{tmn} \cdot i_c \tag{12}$$

Where i_a, i_b and i_c are unit vector templates which are in phase with supply current and are given by-

$$i_a = sin(\omega t) \tag{13}$$

$$i_b = sin(\omega t + 120) \tag{14}$$

$$i_c = sin(\omega t - 120) \tag{15}$$

HYSTERSIS CURRENT CONTROL METHOD

In this method, the actual current continually tracks the command current within a hysteresis-band. Pre-set upper and lower tolerance limits are compared to the extracted error signal. As long as the error is within the tolerance band, no switching action takes place. Switching occurs whenever the error leaves the tolerance band. The hysteresis current control is the fastest method with minimum hardware and software. In this article the hysteresis current control method is used, because of its simplicity of implementation and robustness. This strategy provides satisfactory control of current without requiring extensive knowledge of control system model or its parameters.

SIMULATION WITHOUT UPQC: The simulation waveforms are given as figure 3 for load voltage and current source ,figure 4 shows THD in source current and whereas figure 5 shows THD in load voltage without UPQC

The simulation Circuits and waveforms are given below

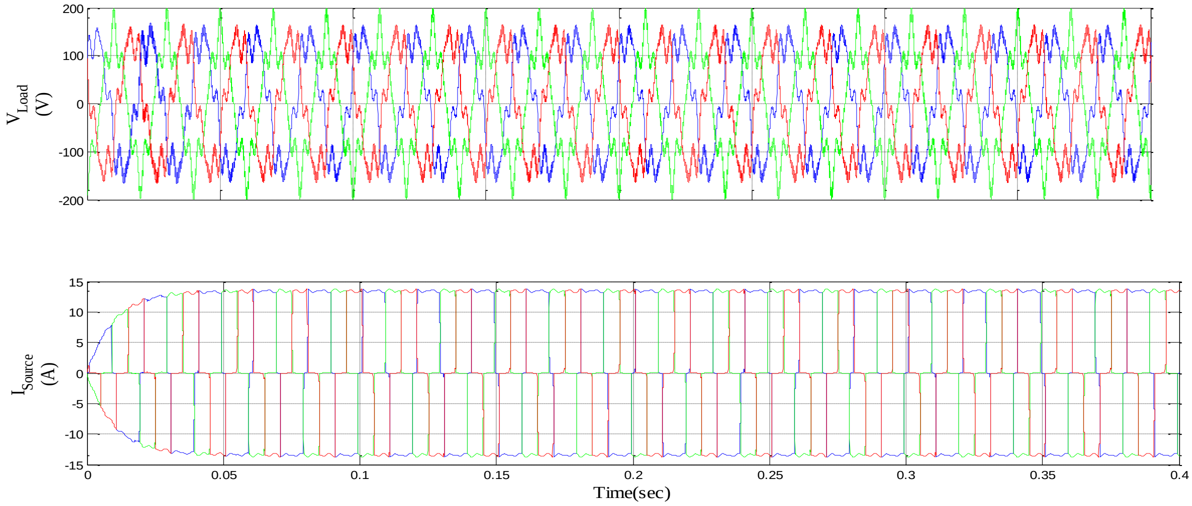

Fig.3. Load Voltage and Source Current without UPQC

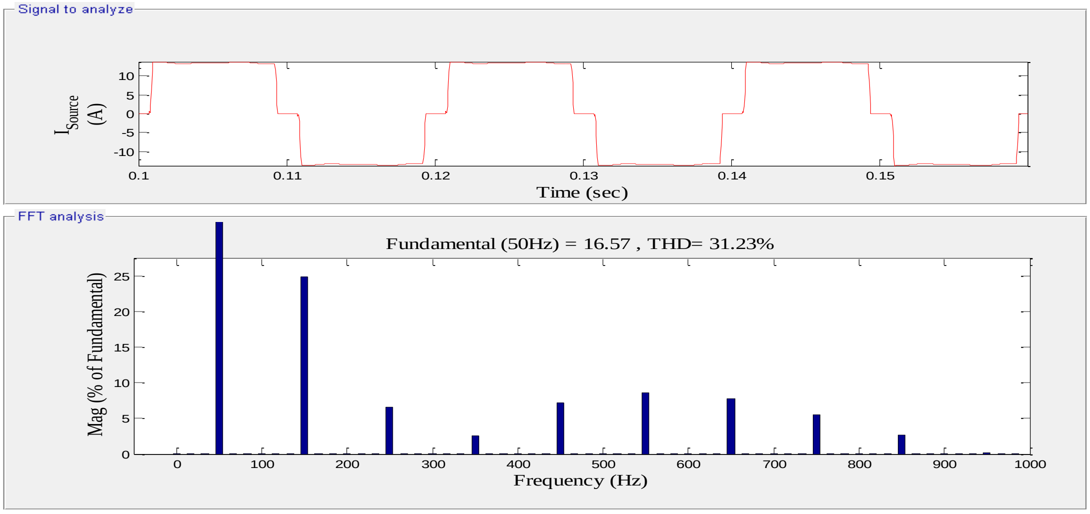

Fig.4. THD in source current without UPQC.

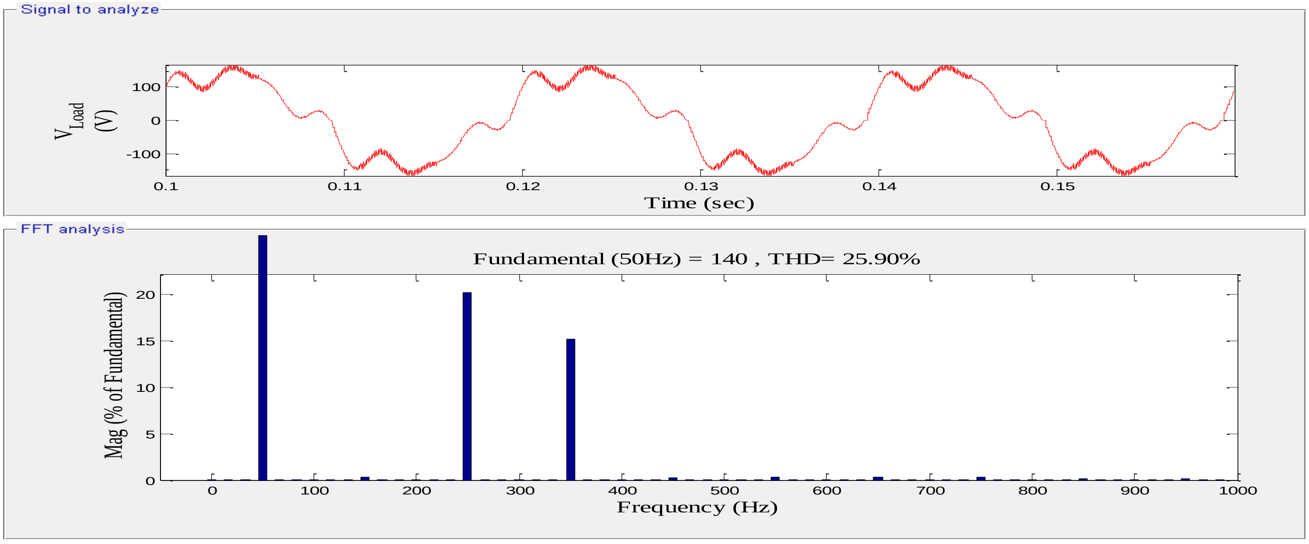

Fig.5. THD in Load Voltage without UPQC

IV. SIMULATION RESULTS AND DISCUSSION

The objectives of work carried out can be summarized as follows:

1. Reduction in the harmonics in the voltage at PCC.
2. Reduction in the harmonics in the source current.

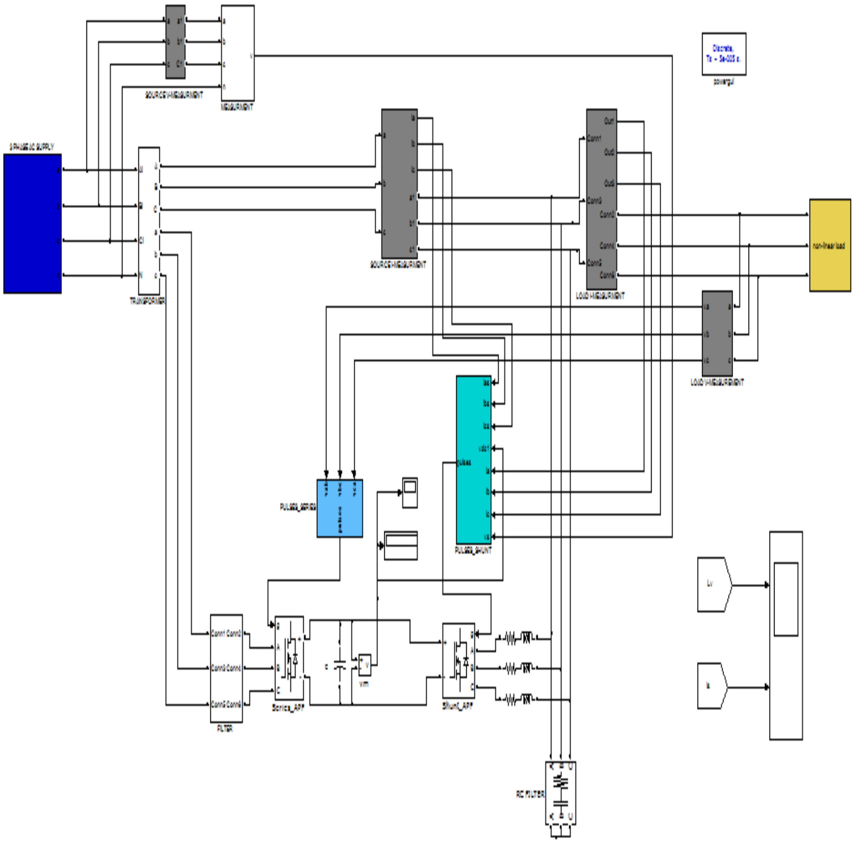

Fig 6 : Simulation model of circuit with rectifier fed RL Load using UPQC.

SIMULATION WITH UPQC

Simulation model of circuit using unified power quality conditioner is given figure 6 below along with their corresponding waveforms of voltage at PCC and source current shown in figure 7. In the present study, hysteresis band gap controllers and Unit Vector Template Technique(UTT) generation theory are used for both series and shunt active power filters. To show the clear operation of UPQC, both Series active power filter and shunt active power filter are put in operation at t = 0.1s so that the distorted current and voltage waveform can be shown in a single diagram along with compensated voltage and current waveforms. To show the improvement in power quality improvement in distribution network as shown in table .The response of UPQC for THD in load voltage and THD in source voltage shown in figure 8 & 9.

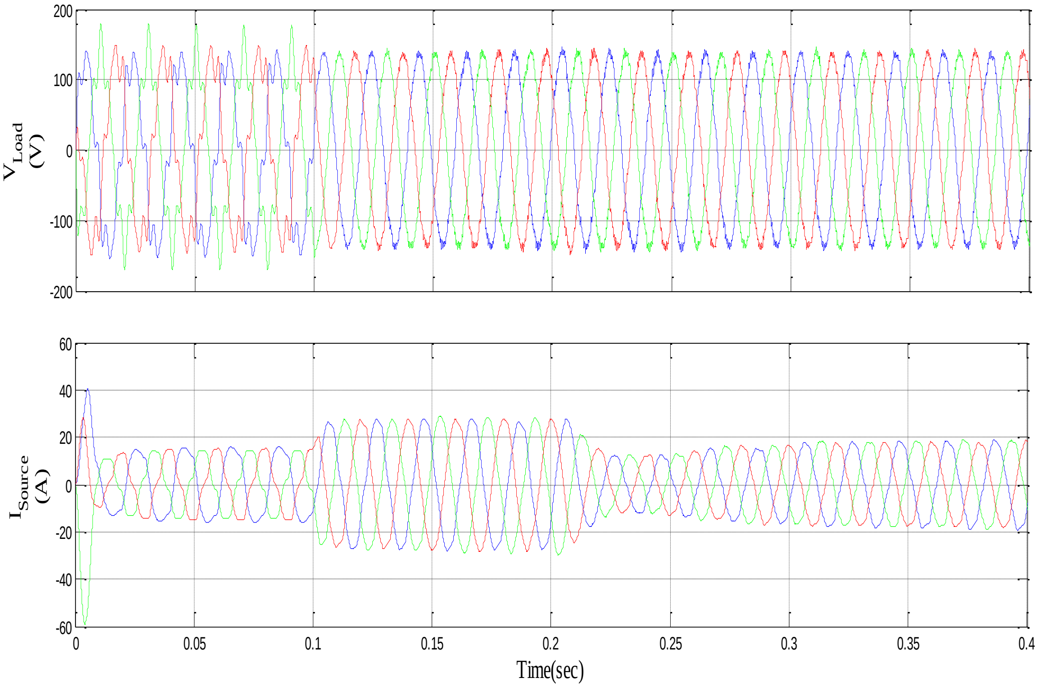

Fig.7. Load Voltage and Source Current with UPQC

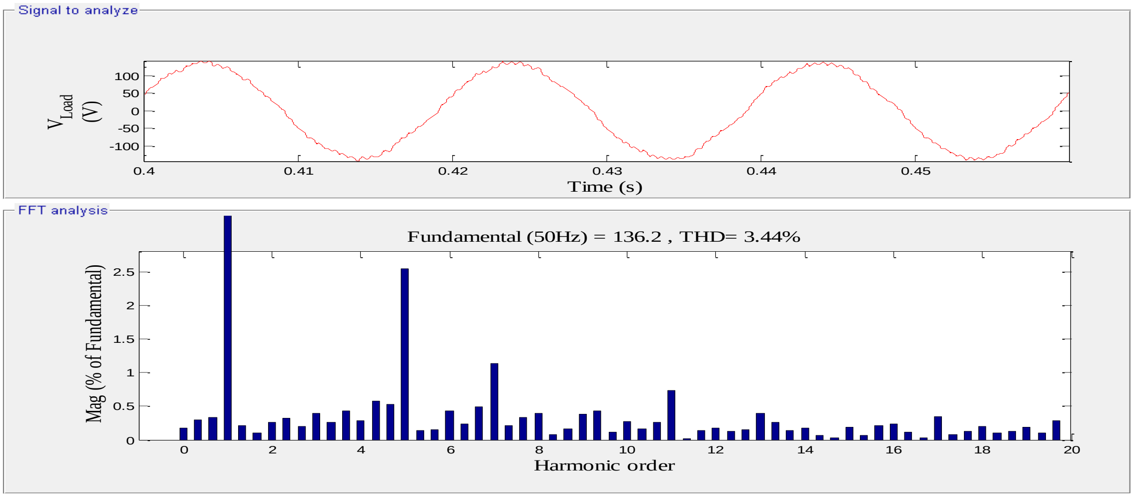

Fig.8. THD in Load Voltage using UPQC.

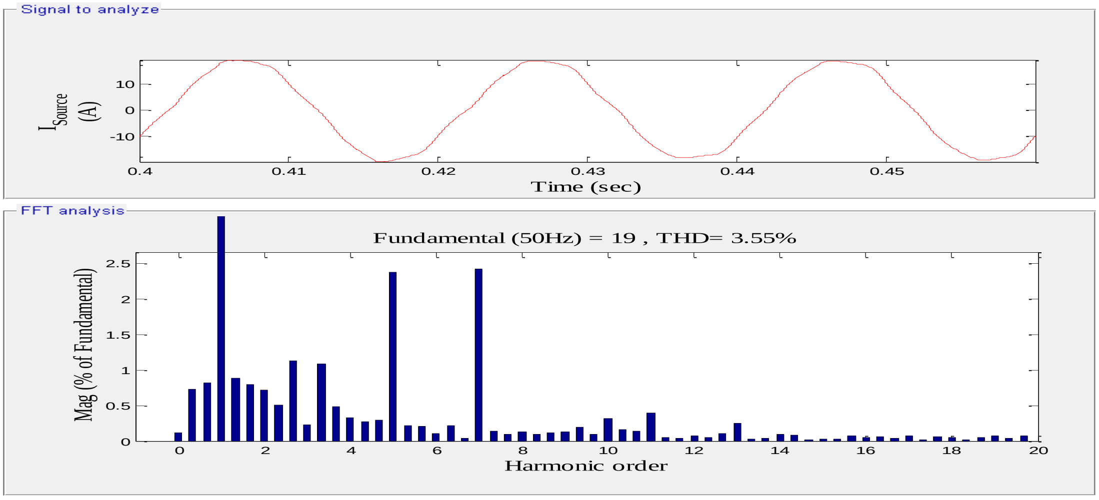

Fig.9. THD in Source Voltage using UPQC.

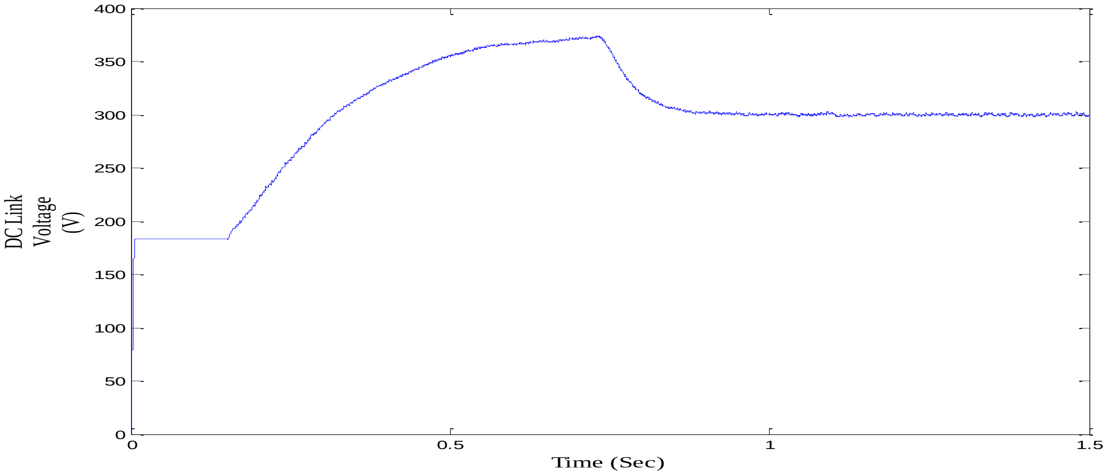

Fig 10 : DC Link Voltage

V. Result & Discussion

The THD in voltage and current is calculated using Fast Fourier Transform and is given by:

$$THD = \frac{\sqrt{\sum_{n}^{\infty} V_n^2}}{V_1} \qquad (1)$$

Where V_n denotes the magnitude of the n harmonic voltage and V_1 is the magnitude of the fundamental voltage. Similar expressions can also be written for current harmonics. The response of DC link voltage corresponding to time shown in figure 10.

Table 1: Simulation Results

Sr No	Without UPQC	With UPQC
1	THD in source current 31.23 %	THD in source current 3.55 %
2	THD in voltage at PCC 25.90 %	THD in voltage at PCC 3.44 %

From Table -1 it can be elucidated that the use of UPQC has considerably reduced the THD in source current from more than 30% to only about 3.55% which is well within the IEEE tolerance limits of 5.0%. The THD in voltage waveform has also reduced from about 25% to about 3.44% which also is within the IEEE tolerance limits.

Thus, the overall quality of the power has considerably improved by employing UPQC.

VI. CONCLUSIONS

The UPQC has become the most important technique for improvement of power in electrical power distribution systems. In this paper, a model for 3-phase UPQC for non-linear loads connected at PCC is simulated using MATLAB/ Simulink for the reduction of harmonics in voltage at PCC. The simulation studies demonstrate the Performance of UPQC

The performance of UPQC is verified with simulation results. From the results, it is clear that the harmonics have reduced by nearly 7-8 times .The THD in voltage at PCC without using UPQC was about 25.90%.The THD in voltage at PCC reduced to about 3.55% after using the UPQC.THD in source current reduced to about 3.44% from more than

30%.Harmonics levels are maintained below IEEE-519 standards.

APPENDIX

The system parameters are used as follows:
Source voltage: 110(ph-ph), 50Hz
Transformer: 1000VA, 240/24, 50Hz
Filter: R=16Ω, 200μF
Load: a three-phase diode bridge
rectifier with R=20Ω and L=100mH on DC side.

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