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Power Quality Improvement by Unified Power Quality Conditioner Based on CSC Topology Using Synchronous Reference Frame Theory

S. Joyal Isac, L. Balakumar and F. Kavin

Saveetha Engineering College,Saveetha Nagar, Chennai, India

Abstract: The objective of our project is to improve power quality using custom power device Unified Power Quality Conditioner (UPQC) based on Current Source Converter (CSC) topology. The major source for power quality problems is the usage of non linear loads which generates undesirable harmonics and also leads to voltage sag and swell. UPQC helps to mitigate the power quality problems like voltage swell, sag and also it eliminates system harmonics. The shunt and series active power filters perform the simultaneous elimination of current and voltage problems. The power fed is linked through a common DC link which is used to maintain constant current. The DC link is connected between the two active power filters through reactor. The reference current and voltage generation for shunt and series converters is obtained using phase locked loop (PLL) and synchronous reference frame (SRF) theory. This theory controls three-phase converters using rotating frame theory by converting source voltage and current into direct and quadrature axes. The proposed UPQC-CSC design has superior performance for mitigating the power quality problems.

Key words: UPQC · SRF · PLL · CSC

INTRODUCTION

Power Quality (PQ) is an important issue to electricity consumers at all levels of usage. The PQ is defined as “Any power problem manifested in voltage, current, or frequency deviations that results in failure or disoperation of customer equipment”. The development of power electronic based equipment has a significant impact on quality of electric power supply. One of the main responsibilities of a utility system is to supply electric power in the form of sinusoidal and currents with appropriate magnitudes and frequency for the customers at the points of common coupling (PCC).

Active power filters (APF) have been proposed as efficient tools for power quality improvement. Active power filters can be classified as series or shunt according to their system configuration. The series APS generally takes care of the voltage based distortions, while shunt APF mitigates current based distortions. The combination of series and shunt power filter is called the unified power-quality compensator (UPQC).

UPQC mitigates the voltage and current based distortion simultaneously as well as independently.

UPQC: Unified Power Quality Conditioner (UPQC) is a multifunction power conditioner that can be used to compensate various voltage disturbance of the power supply, to correct voltage fluctuation and to prevent harmonic load current from entering the power system. It is a custom power device designed to mitigate the disturbances that affect the performance of sensitive and/or critical loads. UPQC has shunt and series compensation capabilities for (voltage and current) harmonics, reactive power, voltage disturbances (including sag, swell, flicker etc.) and power-flow control. Normally, a UPQC[1] consists of two voltage-source inverters with a common dc link designed in single-phase, three-phase three-wire, or three-phase four-wire configurations. One inverter is controlled as a variable voltage source in the series active power filter (APF). The other inverter is controlled as a variable current source in the shunt active power filter (APF). The series APF compensates for voltage supply disturbances (e.g., including harmonics, imbalances, negative and zero sequence components, sag, swell and flickers). The shunt APF converter compensates for load current distortions (e.g., caused by harmonics, imbalances) and reactive power and perform the dc link voltage regulation.

Corresponding Author: S. Joyal Isac, Saveetha Engineering College, Saveetha Nagar, Chennai, India.

Basic Configuration of UPQC: The key components of UPQC are as follows:

Series Inverter: It is a voltage-source inverter connected in series with AC line through a series transformer and acts as a voltage source to mitigate voltage distortions. It 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. In this work hysteresis band PWM is used for the control of inverters. The details of the hysteresis control technique are analysed in the subsequent sections.

Shunt Inverters: It is a voltage source inverter connected in shunt with 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 shunt of the semiconductor switches such that output current follows the reference signal and remains in a predetermined hysteresis band.

Low Pass Filter: it is used to attenuate high frequency components of the voltage at the output of the series converter that are generated by high frequency switching of VSI

High Pass Filter: It is installed at the output of shunt converter to absorb ripples produced due to current switching.

Steady-State Power Flow Analysis of UPQC: The powers due to harmonic quantities are negligible as compared to the power at fundamental component, therefore, the harmonic power is neglected and the steady state operating analysis is done on the basis of fundamental frequency component only. The UPQC is controlled in such a way that the voltage at load bus is always sinusoidal and at desired magnitude. Therefore the voltage injected by series APF must be equal to the difference between the supply voltage and the ideal load voltage. Thus the series APF acts as controlled voltage source. The function of shunt APF is to maintain the dc link voltage at constant level. In addition to this the shunt APF provides the VAR required by the load, such that the input power factor will be unity and only fundamental active power will be supplied by the source. The equivalent circuit of UPQC was shown in the Fig.

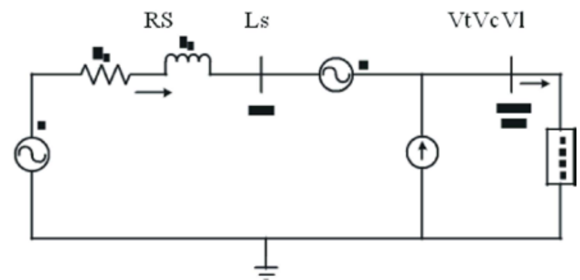


Fig.1.1: Equivalent circuit of a UPQC

Where, Vs = source voltage
Vt = terminal voltage at PCC load
Vl = load voltage
Is = source current
Il = load current
Vc = voltage injected by series APF

The control strategy used in both series and shunt converters are based on Synchronous Reference Frame Theory[2]. The conventional SRF method can be used to extract the harmonics contained in the supply voltages or currents. For current harmonic compensation, the distorted currents are first transferred into two-phase stationary coordinates using á?â transformation (same as in p?q theory). After that the stationary frame quantities are transferred into synchronous rotating frames using cosine and sinus functions from the phase-locked loop (PLL). The sinus and cosine functions help to maintain the synchronization with supply voltage and current. Similar to the p-q theory, using filters, the harmonics and fundamental components are separated easily and transferred back to the a-b-c frame as reference signals for the filter. The conventional SRF algorithm is also known as d-q method and it is based on a-b-c to d-q-0 transformation (park transformation), which is proposed for active filter compensation.

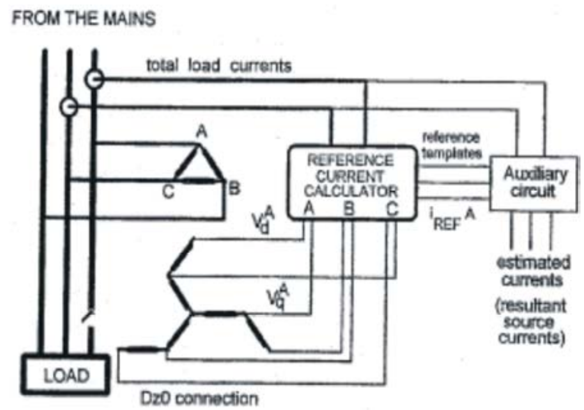
In the SRF-based APF applications in three-phase four-wire (3P4W) systems, voltage and current signals are transformed into the conventional rotating frame (d?q?0). In the SRF method, the transformation angle (ùt) represents the angular position of the reference frame which is rotating at a constant speed in synchronism with the three-phase ac voltage. In non- linear load conditions, harmonics and reactive currents of the load are determined by PLL algorithms[3]. Then, currents with the same magnitude and reverse phase are produced and injected to the power system in order to compensate neutral current, harmonics and reactive power. In the stationary reference frame, á?â?0 coordinates are stationary, while in the SRF, d?q?0 coordinates rotate synchronously with supply voltages. Thus, the angular position of the supply voltage vector shows the angular position of the SRF

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ \text{Sin}(wt) & \sin(wt-2\pi/3) & \sin(wt+2\pi/3) \\ \text{Cos}(wt) & \cos(wt-2\pi/3) & \cos(wt+2\pi/3) \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ V_o \end{bmatrix}$$

The above matrix shows the dq transformation in which three phase voltage is converted into two phase.

$$\begin{bmatrix} V_d \\ Vq \\ V_0 \end{bmatrix} = \sqrt{2/3} \begin{bmatrix} 1/\sqrt{2} & \sin(wt) & \cos(wt) \\ 1/\sqrt{2} & \sin(wt-2\pi/3) & \cos(wt-2\pi/3) \\ 1/\sqrt{2} & \sin(wt+2\pi/3) & \cos(wt+2\pi/3) \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

The above matrix is the inverse transform of dq into three phase. In systems, since the Id component of the current in the "d" coordinate is in phase with voltage, it corresponds to the positive-sequence current. However, the Iq component of the current in the "q" coordinate is orthogonal to the Id component of the current and it corresponds to the negative- sequence reactive current. The I0 component of the current, which is orthogonal to Id and Iq, corresponds to the zero- sequence component of the current. If the Iq component of the current is negative, the load has inductive reactive power. If it is positive, the load has capacitive reactive power. In 3P4W non linear power systems, the Id and Iq components of the current include both oscillating components and average components. The oscillating components of the current correspond to harmonic currents and the average components of the current correspond to the active (Id) and reactive (Iq) currents. In balanced and linear three-phase systems, the load voltage and current signals generally consist of fundamental positive-sequence components. However, in unbalanced and nonlinear load conditions, they include fundamental positive, negative and zero-sequence components. In APF applications, the fundamental positive-sequence components of the signals should be separated in order to compensate harmonics.



Simulation: This chapter discusses the simulation results of shunt active power filter (APF), series active power (APF) filter and the unified power quality conditioner to evaluate the proposed control strategy. The simulation models have been developed in MATLAB/SIMULINK environment.

Simulation Parameters:

Supply = 415V
Frequency = 50Hz
RL load with R = 100?, L = 10mH

Simulation Study of Upqc Topologies: The reference current/voltage extraction capabilities of APF under unbalanced and distorted supply conditions are discussed here. Several case studies are presented to test the overall performance of proposed UPQC in order to mitigate voltage and current related problems. The simulation models have been developed in MATLAB/SIMULINK environment. The models have been operated for non-linear load. The simulation results under voltage sag and swell condition are presented. Additionally, the simulation result under distorted voltage condition is also presented.

Simulation Results of UPQC: In this section the simulation analysis of UPQC is described. In this two filters are used i.e. shunt active power filter and series active power filter. The developed model of UPQC in MATLAB/SIMULINK environment is shown in Fig. The shunt active power filter compensates current disturbances and also maintains the dc link voltage to reference value. While series active power filter compensates voltage related problems for maintaining required load voltage.

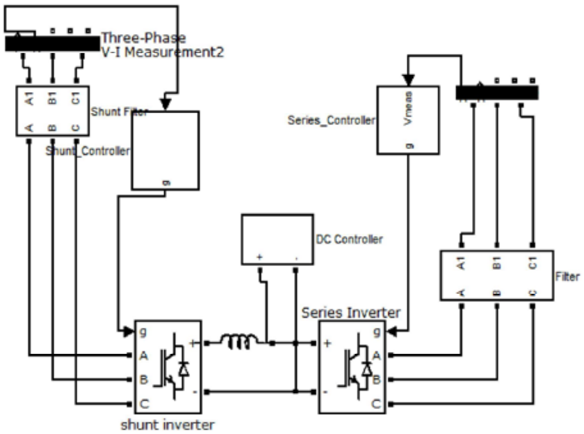


Fig. 2.1 Simulink model of UPQC

Current Harmonic Compensation: Fig. 2.2 shows the compensation current which is measured from the inductor connected in the dc link[4] which helps to compensate the current harmonics at source side.

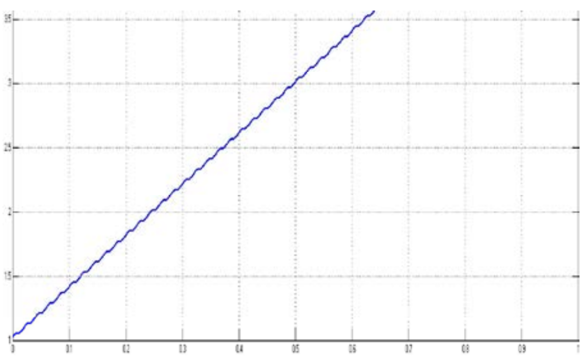


Fig. 2.2: Inductor compensation current

The shunt APF injects a current in such a manner that the source current becomes sinusoidal. At the same time, the shunt APF compensates for the reactive current of the load and improves power factor. Fig 2.3 shows the waveform of source current.

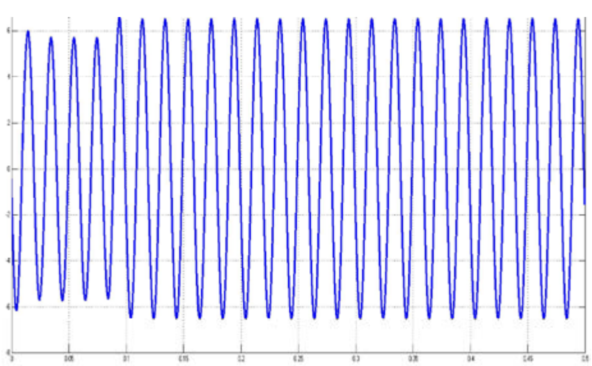


Fig. 2.3: Source current

Figure 2.4 shows the harmonic spectrum of source current for before shunt APF is put in operation. THD of source current is 18.64%. With shunt APF in operation there is a significant reduction in THD[5] at source side current, from 20.73 % to 0.16 %. Shunt inverter is able to reduce the current harmonics entering into the source side. The value of THD obtained from the result shows that the harmonic content are within IEEE standard limit.

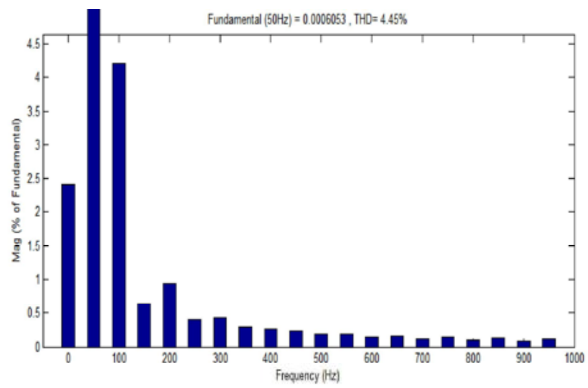


Fig. 2.4: Harmonic spectrum of source current (Before compensation)

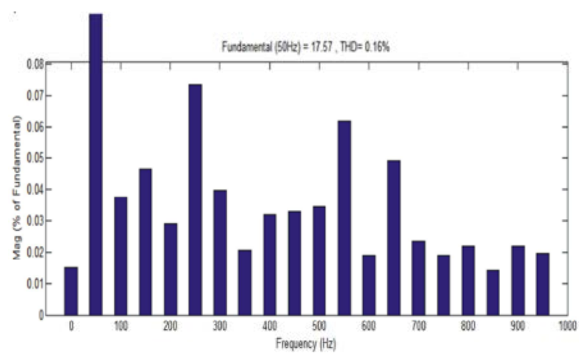


Fig. 2.5: Harmonic spectrum of source current (After compensation)

Voltage Compensation: Figure 2.6 shows the simulation result of load voltage before connecting UPQC. During this breaker operates by closing and opening the switch and accordingly sag and swell are generated and thus there occurs distortion. To study the harmonic compensating capability of UPQC[6], the distortion in utility voltages is introduced deliberately by injecting harmonics. The series APF injects an out-of phase voltage harmonic which is the difference between the desired load voltage and actual supply voltage.

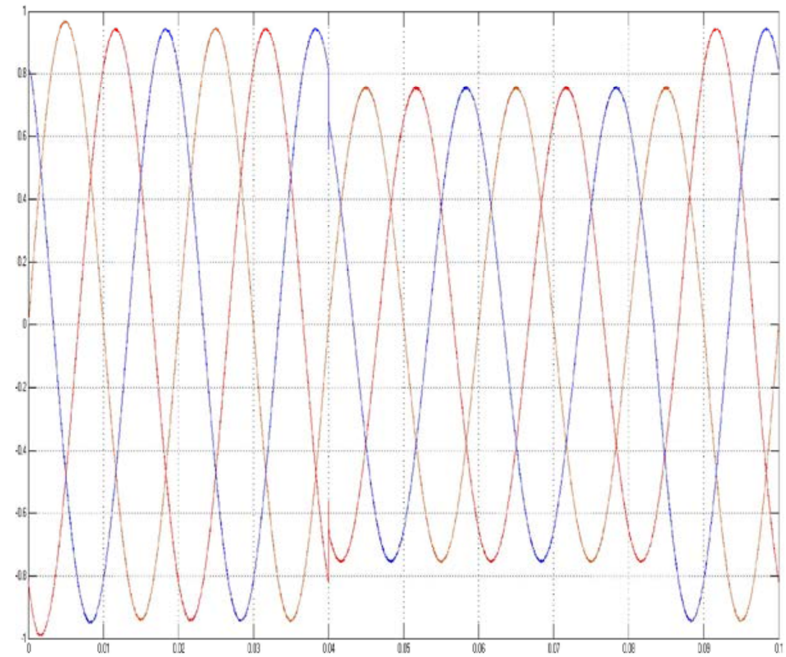


Fig. 2.6: Load voltage before compensation

Figure 2.7 shows the waveform of output voltage after connecting series active power filter at the load side and this is the compensated output waveform. Fig 2.8 shows the harmonic spectrum of load voltage for phase-a after the UPQC is put in operation. THD of load voltage is 20.26%. With the UPQC in operation there is a significant reduction in THD at load side voltage, from 0.99 % to 0.44%. Series APF is able to prevent the harmonics from disturbing load voltage.

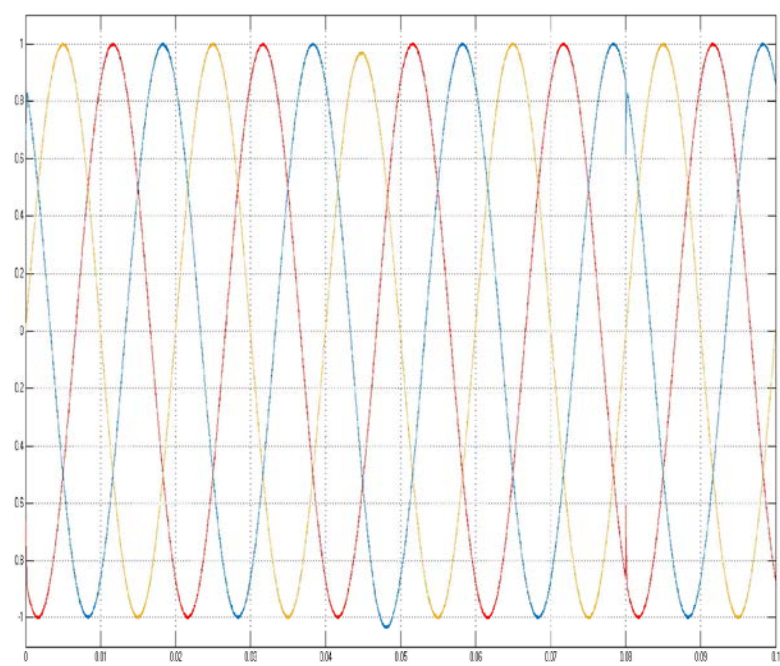


Fig. 2.7: Load voltage after compensation

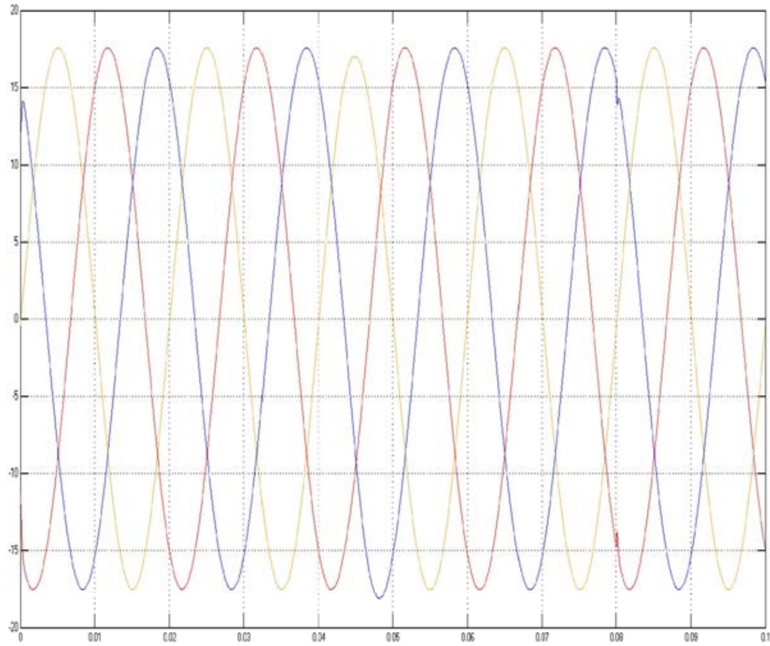


Fig. 2.8: Load current after compensation

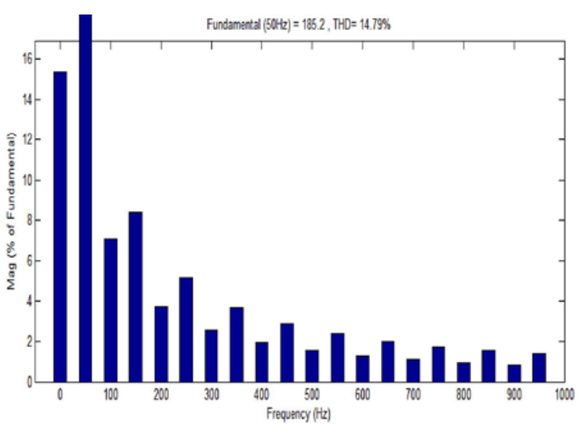


Fig. 2.9: Harmonic spectrum (Before compensation)

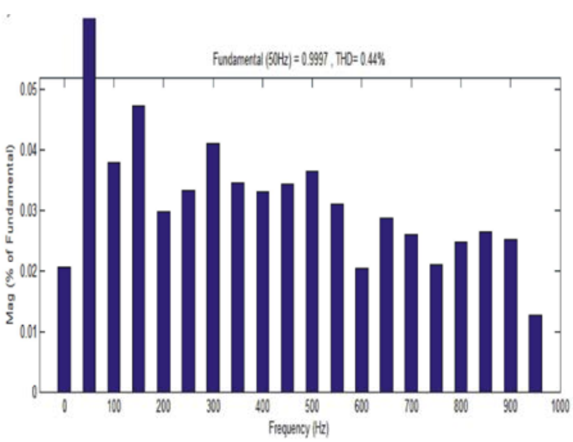


Fig. 2.10: Harmonic spectrum (After compensation)

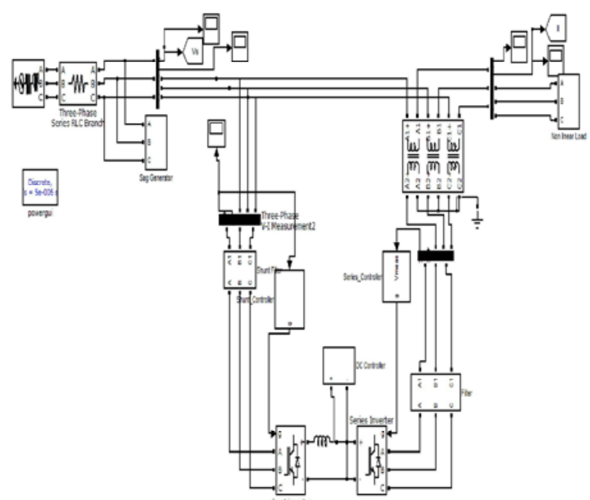


Fig. 2.11: Simulink model of UPQC with control system

CONCLUSION

In this thesis, a Unified Power Quality Conditioner (UPQC) has been investigated for power quality enhancement. UPQC is an advanced hybrid filter that consists of a series active filter (APF) for compensating voltage disturbances and shunt active power filter (APF) for eliminating current distortions. Different power quality problems, their causes and consequences and the available solution have been discussed briefly.

UPQC system configuration is discussed in detail. A conceptual analysis to understand the active and reactive power flow between source and load under different operating condition is carried out. 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. The series and shunt APF models are combined to configure the UPQC model. Using hysteresis band controller the model has been developed in MATLAB/SIMULINK environment. 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.

Future Scope: The UPQC model as developed can be modified to be more effective in eliminating power quality related problems in power system. The various paths in which the presented work can be extended are listed below:

- A laboratory prototype can be made for the developed model.
- The control strategy used here can be modified for three-phase four-wire system under unbalance load.
- The model has been developed for right shunt UPQC configuration. The model can be modified for left shunt UPQC.

Nowadays, generation of electricity from renewable sources has improved very much. Utilizing wind energy and solar energy as a renewable source to generate electricity has developed rapidly. UPQC can be combined with one or several distribution generation (DG) system to provide good quality power to the consumers. Power generated by wind or solar energy can be fed to the DC link through converter to make the UPQC more effective during severe system conditions.

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