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Compensation of Voltage Unbalance using Unified Power Quality Conditioner

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Abstract— Fast evolution of unbalanced loads and non-linear loads leads to lots of power quality problems such as harmonics and unbalance condition in three-phase supplying network. For global solution, Unified Power Quality Conditioner (UPQC) could be the most effective power quality protecting device for sensitive unbalanced loads, which require quality input supply. Active power filters (APFs) that have been explored in shunt, series configurations to compensate for current and voltage based distortions will play on important role for better quality solutions. UPQC can be used instantaneously in voltage or current control in a power distribution system. In the voltage control mode, the UPQC can force the voltage of a distribution bus to be balanced sinusoids. At the same time it can also perform load compensation resulting in the drawing of balanced sinusoidal currents from the distribution system bus. Both these aims are achieved irrespective of unbalance conditions in load currents or load voltages. The revalent simulation results to support the SRF-based control method presented in this paper is done using Matlab/Simulink. The proposed method is also validated through experimental study.

Index Terms— Power Quality, Unified Power Quality Conditioner, Series APFs, Shunt APFs, Synchronous Reference Frame Theory, MATLAB/SIMULINK.

1 Introduction

Power quality issues are gaining significant attention these days as an increasing range of equipment that are sensitive to unbalanced in supply or load side voltages[1]. At the same time an increasing number of power electronic units such as adjustable speed drives (ASD), uninterruptible power supplies (UPS) etc are being used causing rising harmonic pollution in distribution networks [1].Therefore, devices that soften this drawback have been developed. One of them is the unified power quality conditioner (UPQC).

The Unified Power Quality Conditioner (UPQC) is a flexible Methodology for simultaneously active filtering the supply voltage and the load current. In other words, the UPQC keeps critical loads beside voltage disturbance propagating through the power system, and compensates the current of these protected loads to ensure sinusoidal and balanced current drained from the network. Therefore, the UPQC is expected to be one of the most powerful solutions to great capacity loads sensitive to supply voltage flicker/imbalance [1-3]. Usually, the series active filter of a UPQC is used for compensating the supply voltage, whereas the shunt one is used for compensating the load current. Therefore, the series active filter behaves as a controlled voltage source and the shunt active filter behaves as a controlled current source. The conventional control approach of UPQC is not stable and the controller computation is not achieved instantaneously. In proposed method, the new control technique "Synchronous Reference Frame theory" is most efficient for generating the reference current and voltage for the shunt and series APFs

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The compensating voltage reference will comprises a fundamental component, if the UPQC controller is designed for compensating voltage imbalances, as well as all harmonic components in the supply voltage within a given frequency range to be compensated. On the other hand, the compensating current reference comprises a fundamental component to compensate the power factor of the load and all harmonic currents of the nonlinear load.

2 Formation Of UPQC

The UPQC consists of two voltage source inverters connected Back to back with each other sharing a common dc link. One inverter is controlled as a variable voltage source in the series configuration APF, and the other as a variable current source in the shunt configuration APF. Fig. 1 shows a basic system configuration of a general UPQC consisting of the combination of a series APF and shunt APF.

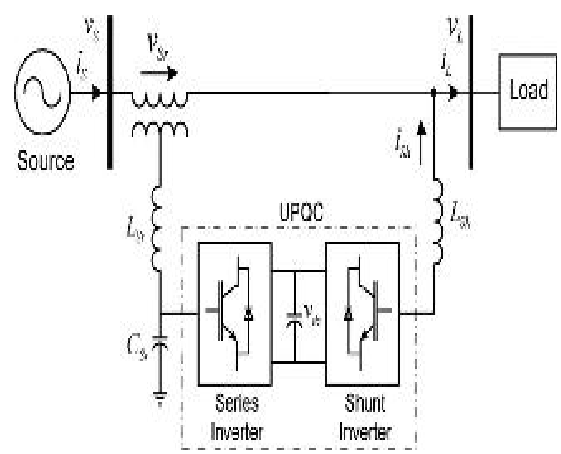

Fig.1 Unified Power Quality Conditioner (UPQC)

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The main aim of the series APF is harmonic isolation between load and supply; it has the capability of voltage flicker/ imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer at Point of Common Coupling (PCC) [4-5]. The shunt APF is used to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc link voltage between both APFs.

The typical of the voltage and current references makes the design of the controls and inverters of the active filters very difficult [5]. Actually, It can be achieved by the efficient control technique, synchronous reference frame theory (SRF) it's very stable time domain method since the controller deals mainly with the dc quantities & prompt computation.

3 Control Method

SRF theory is based on the transformation of currents in synchronously rotating d–q frame [10].Sensed inputs Vsa, Vsb, Vsc, Isa, Isb, Isc are fed to the controller. Voltage signals have been handled by a phase-locked loop (PLL) to generate unit voltage templates (sine and cosine signals). Current signals have been transmuted to d–q frame, where these signals are filtered and transmuted back to a-b-c frame, which are fed to PWM signal generator to make concluding switching signals provide for to the shunt inverter [12-13]. Similar to the series inverter voltage signals have been transformed into d-q frame, where these signals are filtered and transformed back to a-b-c frame, which are provide for to a PWM Signal generator to make concluding switching signals fed to the series inverter. In the balanced and linear three-phase systems, the load voltage and current signals generally comprise of fundamental positive-sequence components. However, in unbalanced and nonlinear load conditions, they embrace fundamental positive-sequence, negative-sequence, and zero-sequence components. In APF applications, the fundamental positive-sequence components of the signals should be divided in order to compensate the harmonics.

A. REFERENCE SIGNAL GENERATION FOR SERIES INVERTER

The purpose of the series APF is to compensate the voltage trouble in the source side, which is due to the fault in the distribution line at the PCC [9]. The series APF control algorithm computes the reference value to be injected by the series APF transformers, relating the positive-sequence component with the load side line voltages. The proposed series APF reference voltage signal generation system is shown in Fig. 2.The supply voltages are transformed to d-q-0 coordinates. The d axes voltage consists of average and oscillating components of source voltages. The average voltage vSd is calculated by using low pass filter.

$$\begin{bmatrix} V_{s0} \\ V_{sd} \\ V_{sq} \end{bmatrix} = 2/3 \begin{bmatrix} 1/2 & 1/2 & 1/2 \\ \sin\omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos\omega t & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix}$$

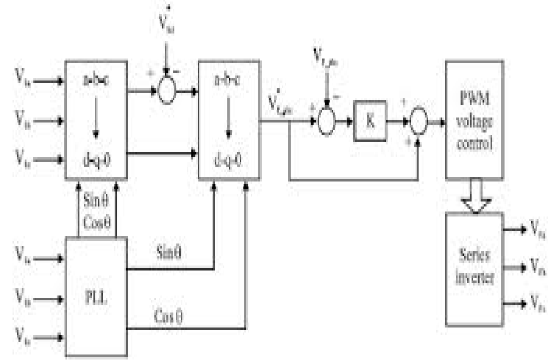

Fig.2 Control circuit for series APF

The load side reference voltages are calculated.The switching signals are produced by associating reference Voltages (∗vLabc) and the load voltages (vLabc) and via sinusoidal PWM controller.

$$\begin{bmatrix} v_{La}^* \\ v_{Lb}^* \\ v_{Lc}^* \end{bmatrix} = 2/3 \begin{bmatrix} \sin\omega t & \cos\omega t & 1 \\ \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t - \frac{2\pi}{3}) & 1 \\ \sin(\omega t + \frac{2\pi}{3}) & \sin(\omega t - \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} V_{sd} \\ 0 \\ 0 \end{bmatrix}$$

These produced three-phase load reference voltages are associated with load line voltages and errors are then processed by PWM controller to make the required switching signals aimed at series APF IGBT switches.

B. REFERENCE SIGNAL GENERATION FOR SHUNT INVERTER

The shunt APF described in this paper used to compensate the current unbalance and created by the nonlinear load.In three phase systems, since the *id* component of the current in the "*d*" coordinate is in phase with voltage, it corresponds to the positive-sequence current [13].

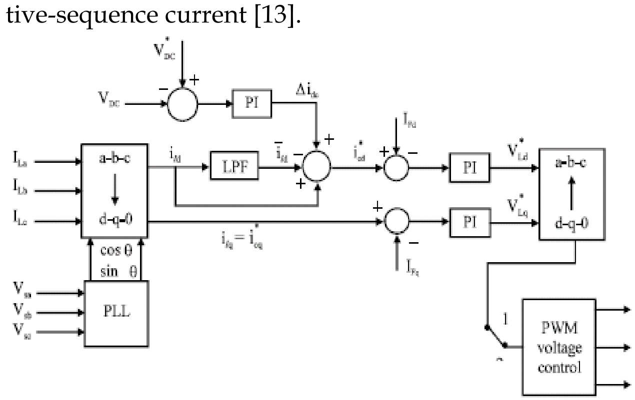

Fig.3 Control circuit for shunt APF

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However, the *iq* component of the current in the "*q*" coordinate is orthogonal to the *id* component of the current, and it relates to the negative sequence Reactive current. The *i*0 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.

$$\begin{bmatrix} Is0 \\ Isd \\ Isq \end{bmatrix} = 2/3 \begin{bmatrix} 1/2 & 1/2 & 1/2 \\ \sin\omega t & \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t + \frac{2\pi}{3}) \\ \cos\omega t & \cos(\omega t - \frac{2\pi}{3}) & \cos(\omega t + \frac{2\pi}{3}) \end{bmatrix} \begin{bmatrix} Isa \\ Isb \\ Isc \end{bmatrix}$$

If it is positive, the load has capacitive reactive power. In three phase system, nonlinear power systems, the *id* and *iq* components of the current contain both oscillating components and average components.

$$\begin{bmatrix} ILa* \\ ILb* \\ ILc* \end{bmatrix} = 2/3 \begin{bmatrix} \sin\omega t & \cos\omega t & 1 \\ \sin(\omega t - \frac{2\pi}{3}) & \sin(\omega t - \frac{2\pi}{3}) & 1 \\ \sin(\omega t + \frac{2\pi}{3}) & \sin(\omega t - \frac{2\pi}{3}) & 1 \end{bmatrix} \begin{bmatrix} Isd \\ 0 \\ 0 \end{bmatrix}$$

The oscillating components of the current correspond to harmonic currents, and the average components of the current resemble to the active and reactive currents. The average voltage is calculated by using low pass filter.The voltage drawn from the dc link capacitance is compared to the constant voltage value, the result is manipulated by pi controller and this resultant current is compared with oscillatory and average component of source current. At last, the load side reference voltages are calculated. The switching signals are produced by comparing reference voltages (∗iLabc) and the load voltages (iLabc) and via sinusoidal PWM controller. The errors are calculated by PWM controller to make the essential switching signals used for shunt APF IGBT switches.

4 Simulation Models

In this paper deals a new control technique for reference signal generation of an UPQC. It processed by the simulation results of UPQC given by MATLAB/Simulink under unbalanced load conditions of three phase system. The simulated UPQC system parameters are given in Table I. The effects are stated before and after UPQC system are operate and when the UPQC system is operated, the load has changed and dynamic response of the system is tested. The offered control method has been observed unbalanced voltage conditions.

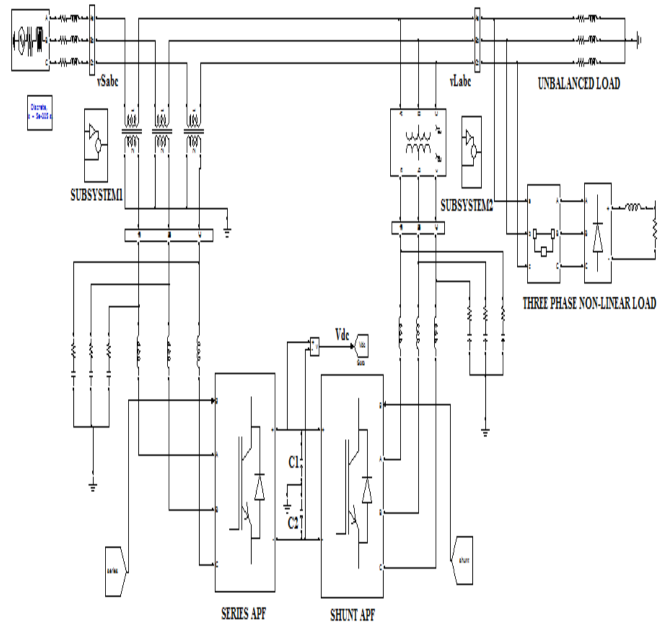

Fig. 4. The UPQC block diagram in MATLAB Simulink

Using this Unified power quality conditioner, compensate the unbalanced load voltage and current which is accomplished by Simulink/MATLAB model. The control method for generate the reference voltage and current signals of series active power filter and shunt active power filter.

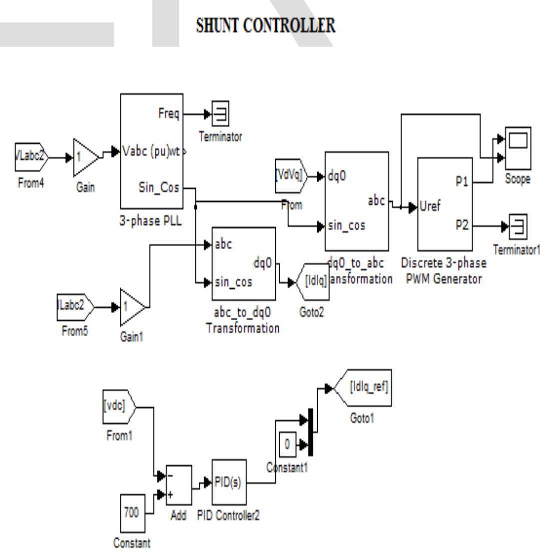

Fig.5 Simulink Model for shunt APF

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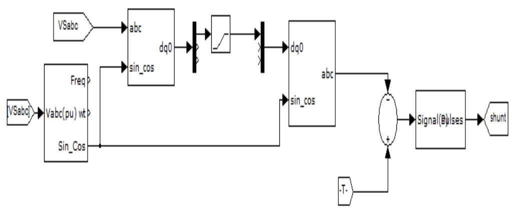

Fig.7 Simulink Model for series APF

The shunt active power filters is mainly for mitigating current related problems.Harmonic currents that cancel the harmonic currents from a non-linear load. In this configuration, the filter is connected in parallel with the load being compensated.The proposed control technique has been estimated and tested under dynamical and steady-state load conditions.

TABLE 1
SYSTEMS PARAMETERS OF UPQC

source	Voltage Vs_{abc}	415V (L-L) rms
	System frequency f_s	50Hz
Dc-link	Voltage V_{dc}	800V
	Capacitor C_{dc}	4000 µF
Load	Unbalanced	25+j0.6, 42+j0.9,61+j0.3
	Rectifier fed	50 + j 31.4
Series APF	Single phase transformers	2kVA each, 200V/200V, Leakage reactance 2%
Shunt APF	Three phase (Y-Y) transformer	6kVA, Leakage reactance 6%

5 PERFORMANCE OF UPQC

The reaction of UPQC for Voltage mitigating problems, Current mitigating problems with shunt APF and series APF is shown in Figure given below. Both APFs are put into operation at changed instant of time for the conception of performance of both the shunt APF and the series APF. It is observed that the load voltages are balanced; sinusoidal and in-phase with the current even under non-sinusoidal utility current.

The control method for generate the reference voltage and current signals of series active power filter and shunt active power filter.

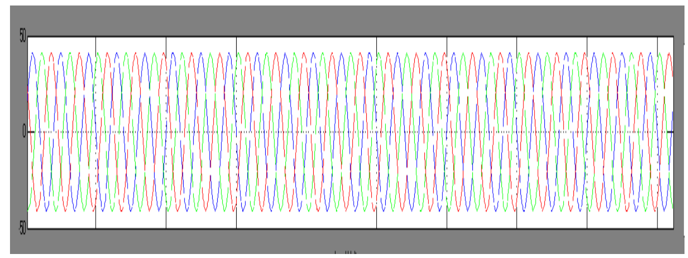

Fig.7 Source Voltage after Compensation

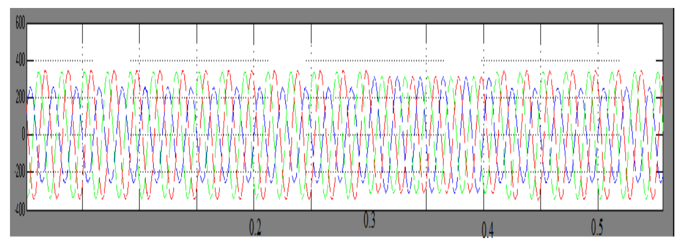

Fig.8 Load Voltage when unbalanced occurred from 0.3 to 0.4 sec

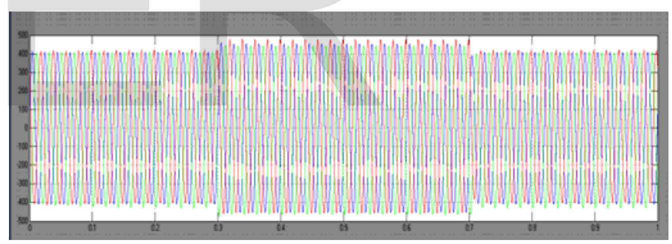

Fig.9 Load current when fault occurred from 0.3 to 0.7

Fig 10 and 11 shows Voltage and Current injection through series and shunt transformer to the line for compensating unbalanced load voltage and load current.

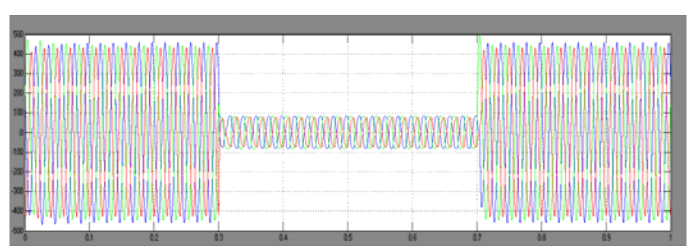

Fig.10 Current injected through shunt APF

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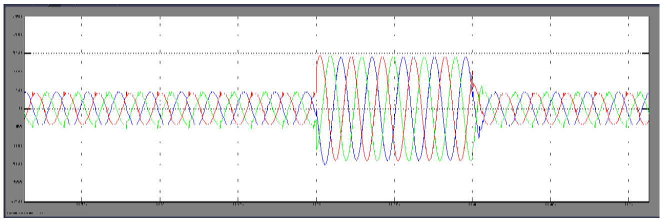

Fig.11 Voltage injected through series APF

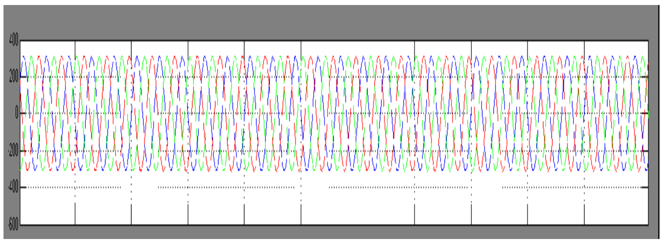

Fig.12 Compensating Load Current

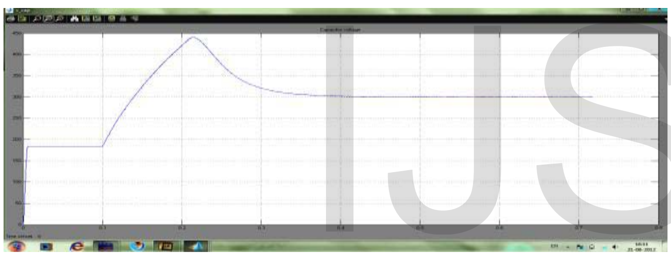

Fig.13 DC Link Voltage

Fig 13 shows Dc link Voltage. It maintained as constant across the dc link capacitance between shunt and series APFs

6 Conclusion

In this paper, a theoretical study for the parameters of UPQC has been agreed out during voltage unbalance and current unbalance. Likewise that, unbalance condition has been considered to evaluate the performance of series and shunt active power filters in compensating the unbalance of both load voltages and load currents. The modules on each control, series and shunt APF are the most important factors in compensating process. Some parameters are affecting the performance of UPQC to enhance the voltage unbalance such as the optimal capacitors values of the shunt APF. On the other hand, UPQC performance mainly depends upon how accurately and quickly reference signals are derived and DC voltage in order to regulate DC bus. Therefore, a better choice is to apply an intelligent technique to improve the UPQC parameter values. Meanwhile, the series APF isolates the loads voltages and source voltage, the shunt APF provides three-phase balanced and rated currents for the loads.

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