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Research Paper

REDUCTION OF THD IN POWER SYSTEM USING GENERALIZED UPQC

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This paper deals with Unified Power Quality Conditioners (UPQC's), which aim at the integration of series-active and shunt-active filters. The main purpose of a UPQC is to compensate for voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems or industrial power systems. This paper presents a modified Synchronous-Reference Frame (SRF)-based control method to Shunt active filter and Instantaneous PQ (IPQ) theory based control technique for series active filter to compensate Power-Quality (PQ) problems through a three-phase four-wire Unified PQ Conditioner (UPQC) under unbalanced and distorted load conditions. The proposed UPQC system can improve the power quality at the point of common coupling on power distribution systems under unbalanced and distorted load conditions. The simulation results based on Matlab/Simulink are discussed in detail in this paper.

Keywords: Unified Power Quality Conditioner (UPQC), Phased Locked Loop (PLL), Active Power Filter (ACP), Synchronous Reference Frame (SRF)

INTRODUCTION

Power quality has become an important factor in power systems, for consumer and household appliances with proliferation of various electric and electronic equipment and computer systems. The main causes of a poor power quality are harmonic currents, poor power factor, supply-voltage variations, etc. A technique of achieving both active current distortion compensation, power factor correction and also mitigating the supply-voltage variation at the load side is compensated by unique device of UPQC presented in this paper.

This paper deals with Unified Power Quality Conditioners (UPQC's), which aim at the integration of series active and shunt-active filters. The main purpose of a UPQC is to

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compensate for supply voltage flicker/ imbalance, reactive power, negative-sequence current, and harmonics. In other words, 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.

In this paper, much attention is paid to the generalized UPQC consisting of a series active and shunt-active filter. The series-active filter eliminates supply voltage flicker/ imbalance from the load terminal voltage, and forces an existing shunt-passive filter to absorb all the current harmonics produced by a nonlinear load. Elimination of supply voltage flicker, however, is accompanied by low frequency fluctuation of active power flowing into or out of the series-active filter. The shunt-active filter performs dc-link voltage regulation, thus leading to a significant reduction of capacity of the dc capacitor.

DEFINITION OF POWER QUALITY

Power quality is a term that means different things to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as "the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment." As appropriate as this description might seem, the limitation of power quality to "sensitive electronic equipment" might be subject to disagreement. Electrical equipment susceptible to power quality or more appropriately to lack of power quality would fall within a seemingly boundless domain.

All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance. All of these devices and others react adversely to power quality issues, depending on the severity of problems.

A simpler and perhaps more concise definition might state: "Power quality is a set of electrical boundaries that allows a piece of equipment to function in its intended manner without significant loss of performance or life expectancy." This definition embraces two things that we demand from an electrical device: performance and life expectancy. Any power-related problem that compromises either attribute is a power quality concern. In light of this definition of power quality, this chapter provides an introduction to the more common power quality terms. Along with definitions of the terms, explanations are included in parentheses where necessary. This chapter also attempts to explain how power quality factors interact in an electrical system.

UNIFIED POWER QUALITY CONDITIONER (UPQC)

The provision of both DSTATCOM and DVR can control the power quality of the source current and the load bus voltage. In addition, if the DVR and STATCOM are connected on the DC side, the DC bus voltage can be regulated by the shunt connected DSTATCOM while the DVR supplies the required energy to the load in case of the transient disturbances in source voltage. The configuration of such a device (termed as Unified Power Quality Conditioner (UPQC)) is shown in Figure 1. This is a versatile device similar to a UPFC. However, the control objectives of a UPQC are quite different from that of a UPFC.

Figure 1: A Unified Power Quality Conditioner

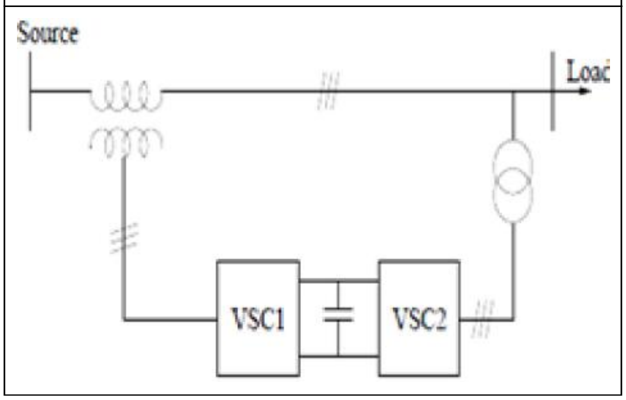
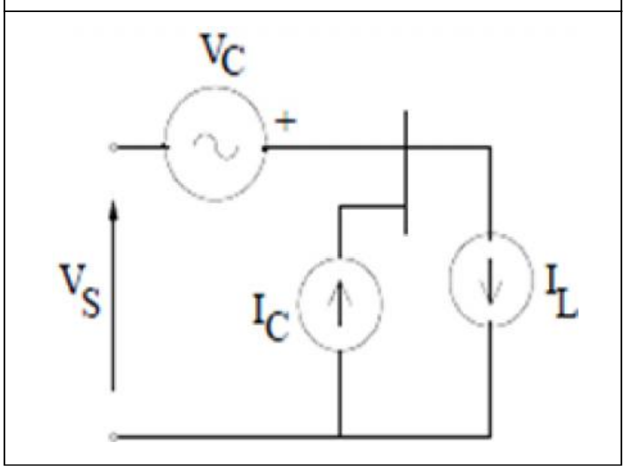


Figure 2: Equivalent Circuit of Ideal UPQC



A Unified Power Quality Conditioner (UPQC) is a device that is similar in construction to a Unified Power Flow Conditioner (UPFC). The UPQC, just as in a UPFC, employs two voltage source inverters (VSIs) that connected to a dc. energy storage capacitor. One of these two VSIs is connected in series with ac. line while the other is connected in shunt with the ac system. An UPQC that combines the operations of a Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Regulator (DVR) together.

One of the serious problems in electrical systems is the increasing number of electronic components of devices that are used by industry as well as residences. These devices, which need high-quality energy to work properly, at the same time, are the most responsible ones for injections of harmonics in the distribution system. Therefore, devices that soften this drawback have been developed.

One of them is the Unified Power Quality Conditioner (UPQC). It consists of a shunt active filter together with a series-active filter. This combination allows a simultaneous compensation of the load currents and the supply voltages, so that compensated current drawn from the network and the compensated supply voltage delivered to the load are sinusoidal, balanced and minimized. The series and shunt-active filters are connected in a back-to-back configuration, in which the shunt converter is responsible for regulating the common DC-link voltage.

SRF Methods

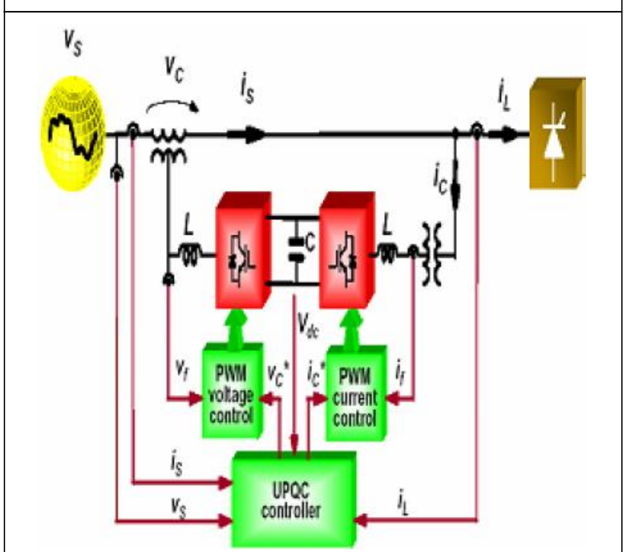
Among the several methods presented in the literature, the Synchronous Reference Frame method (SRF) is one of the most common and probably it is widely used method. This section is organized as to describe succinctly the SRF methods. The three methods presented in this section with some results obtained with the above mentioned methods. The nonlinear load considered is a three-phase diode bridge rectifier. A Synchronous Reference Theory (SRF)

In the SRF (Akagi *et al.*, 2007), the load current signals are transformed into the conventional rotating frame d-q. If theta is the transformation angle, the transformation is defined by:

$$\begin{bmatrix} X_d \\ X_q \\ X_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\theta) & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{4\pi}{3}\right) \\ -\sin(\theta) & \sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{4\pi}{3}\right) \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} X_a \\ X_b \\ X_c \end{bmatrix} \quad ...(1)$$

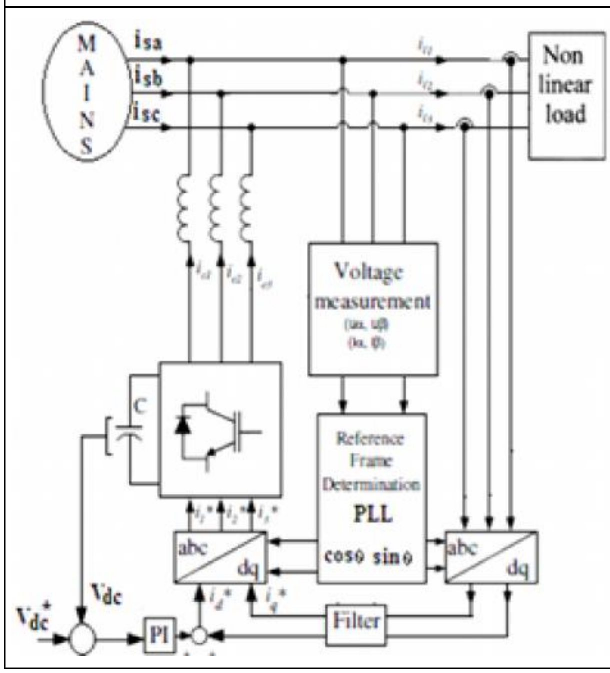
Figure 3 shows the basic configuration of synchronous reference frame. In the SRF is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltages. In the SRF is a time varying angle that represents the angular position of the reference frame which is rotating at constant speed in synchronism with the three phase ac voltages. To implement the SRF method some kind of synchronizing system should be used. In Akagi *et al.* (2007) Phase-Locked Loop (PLL) is used for the

Figure 3: Control Scheme Using UPQC



implementation of this method. In this case the speed of the reference frame is practically constant, that is, the method behaves as if the reference frame's moment of inertia is infinite. The fundamental currents of the *d-q* components are now dc values. The harmonics appear like ripple. Harmonic isolation of the *d-q* transformed signal is achieved by removing the dc offset. This is accomplished using High Pass Filters (HPF). In spite of a high pass filter, a low pass filter is used to obtain the reference source current in *d-q* coordinates.

Figure 4: Basic Principle of SRF



Instantaneous Current Component (i_d–i_q) Theory

The Modified Synchronous Frame method is presented in Graovac *et al.* (2007). It is called the instantaneous current component (i_d-i_q) method. This is similar to the SRF frame method. The transformation angle is now obtained with the voltages of the ac network. The major difference is that, due to voltage harmonics and imbalance, the speed of the reference frame is no longer constant. It varies instantaneously depending of the waveform of the three phase voltage system. In this method the compensating currents are obtained from the instantaneous active and reactive current components and of the nonlinear load. In the same way, the mains voltages *V*(*a*, *b*, *c*) and the polluted currents *I*(*a*, *b*, *c*) in ~- components must be calculated as given by (2), where C is Clarke Transformation Matrix. However, the load current components are derived from a synchronous reference frame based on the Park transformation, where represents the instantaneous voltage vector angle (3).

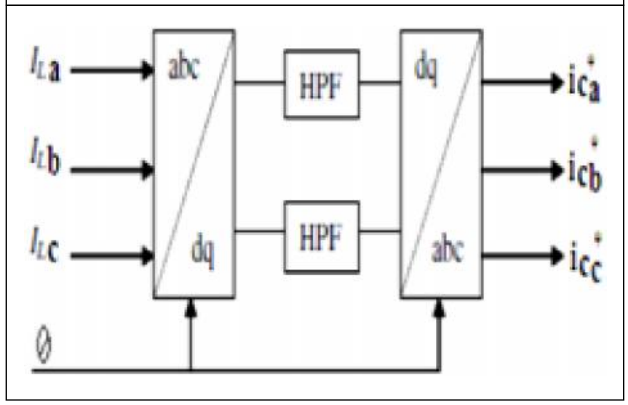
$$\begin{bmatrix} i1\sim \\ i1 \end{bmatrix} = [c]\begin{bmatrix} Ila \\ Ilb \\ Ilc \end{bmatrix} \quad ...(2)$$

$$\begin{bmatrix} i1d \\ i1q \end{bmatrix} = \begin{bmatrix} \cos(^{-}) & \sin(^{-}) \\ -\sin(^{-}) & \cos(^{-}) \end{bmatrix}\begin{bmatrix} i1\sim \\ i1 \end{bmatrix}$$

$$^{-} = \tan^{-1}\frac{v}{v\sim} \quad ...(3)$$

Figure 5 shows the block diagram SRF method. Under balanced and sinusoidal mains voltage conditions angle ¯ is a uniformly increasing function of time. This transformation angle is sensitive to voltage harmonics and unbalance; therefore *d*¯/*dt* may not be constant over a mains period. With transformation (2) and (3) the direct voltage component is:

Figure 5: Principal of the Synchronous Reference Frame Method



$$\begin{bmatrix} ild \\ ilq \end{bmatrix} = \frac{1}{\sqrt{v\sim^2 + v^2}}\begin{bmatrix} v\sim & v \\ -v & v\sim \end{bmatrix}\begin{bmatrix} il\sim \\ il \end{bmatrix}$$

$$\begin{bmatrix} ic\sim \\ ic \end{bmatrix} = \frac{1}{\sqrt{v\sim^2 + v^2}}\begin{bmatrix} v\sim & -v \\ v & v\sim \end{bmatrix}\begin{bmatrix} icd \\ icq \end{bmatrix}$$

$$\begin{bmatrix} Icomp,\ a \\ Icomp,\ a \\ Icomp,\ a \end{bmatrix} = [c]^T\begin{bmatrix} ic\sim \\ ic \end{bmatrix} \quad ...(4)$$

Figure 6: Simulink Diagram of Proposed UPQC System

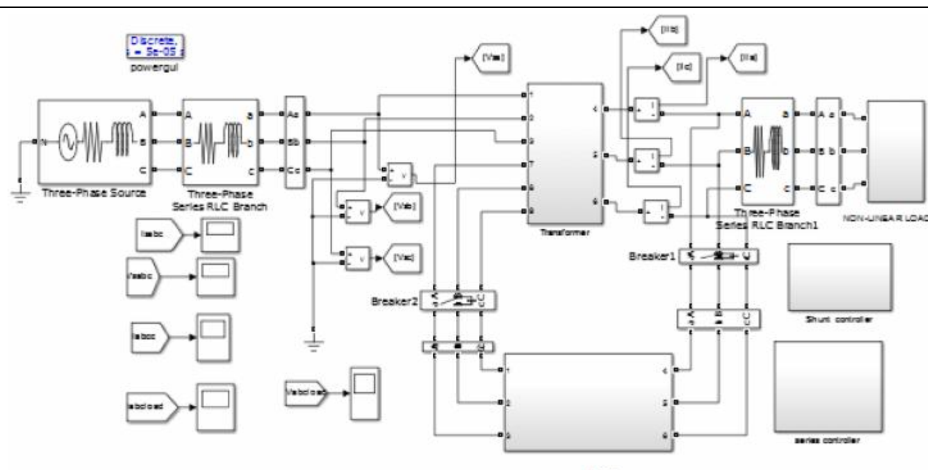


Figure 7: Subsystem of UPQC

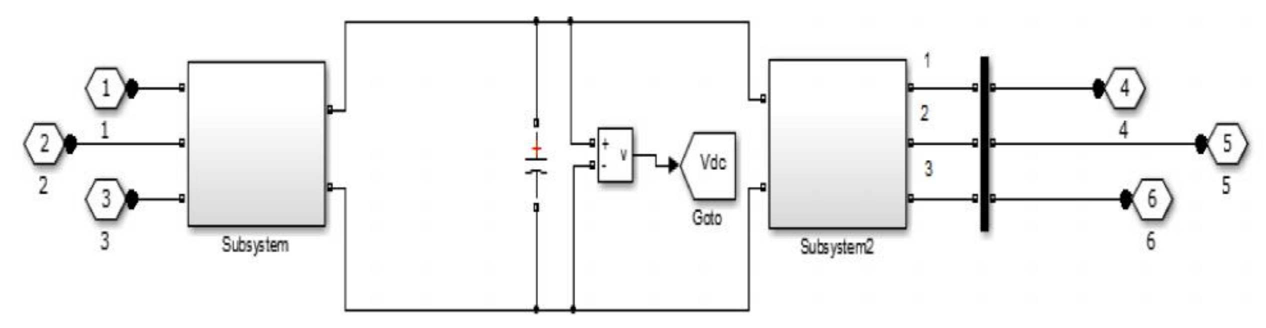


Figure 8: Simulink of Series Active Filter

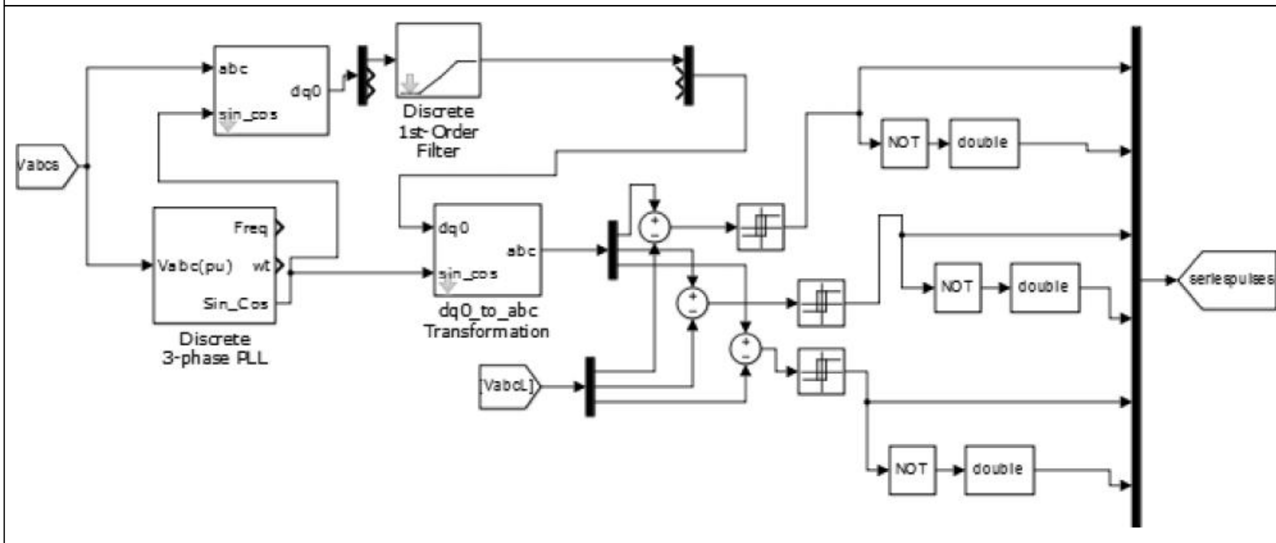
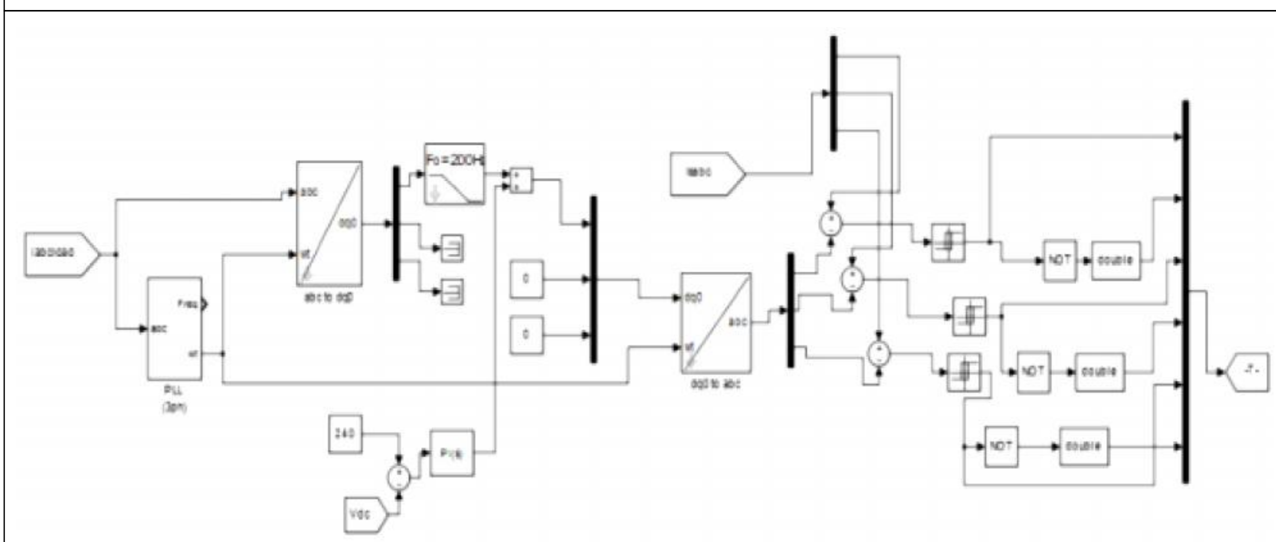


Figure 9: Simulink of Shunt Active Filter



SIMULATION RESULTS

In this study a new control algorithm for UPQC is evaluated by using simulation results given in Matlab/simulink software. In simulation studies, the results are specified before and after UPQC system are operated. In this system a breaker is connected such that if the breaker is opened UPQC is disconnected and if breaker is closed UPQC is connected.

The proposed UPQC control algorithm has the ability to compensate both harmonics and reactive power of the load is eliminated.

Figure 10: Source Current Without Compensation

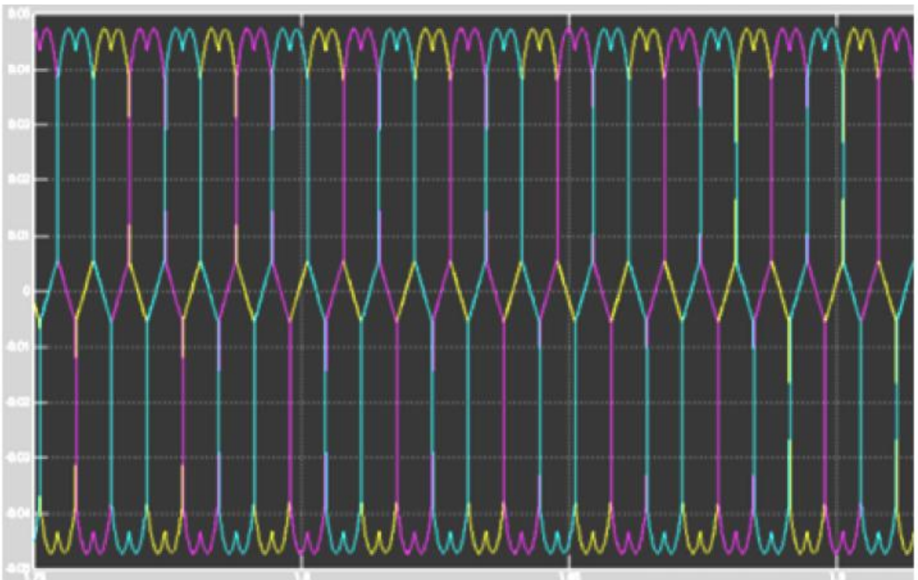


Figure 11: Source Voltage with Compensation

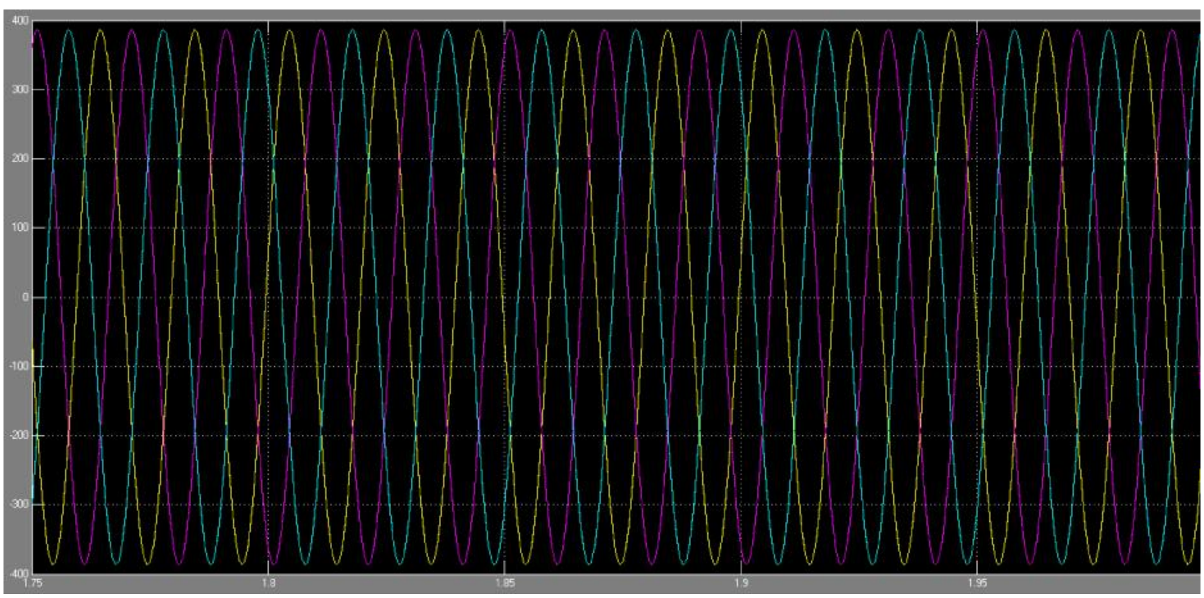


Figure 12: Source Current with Compensation

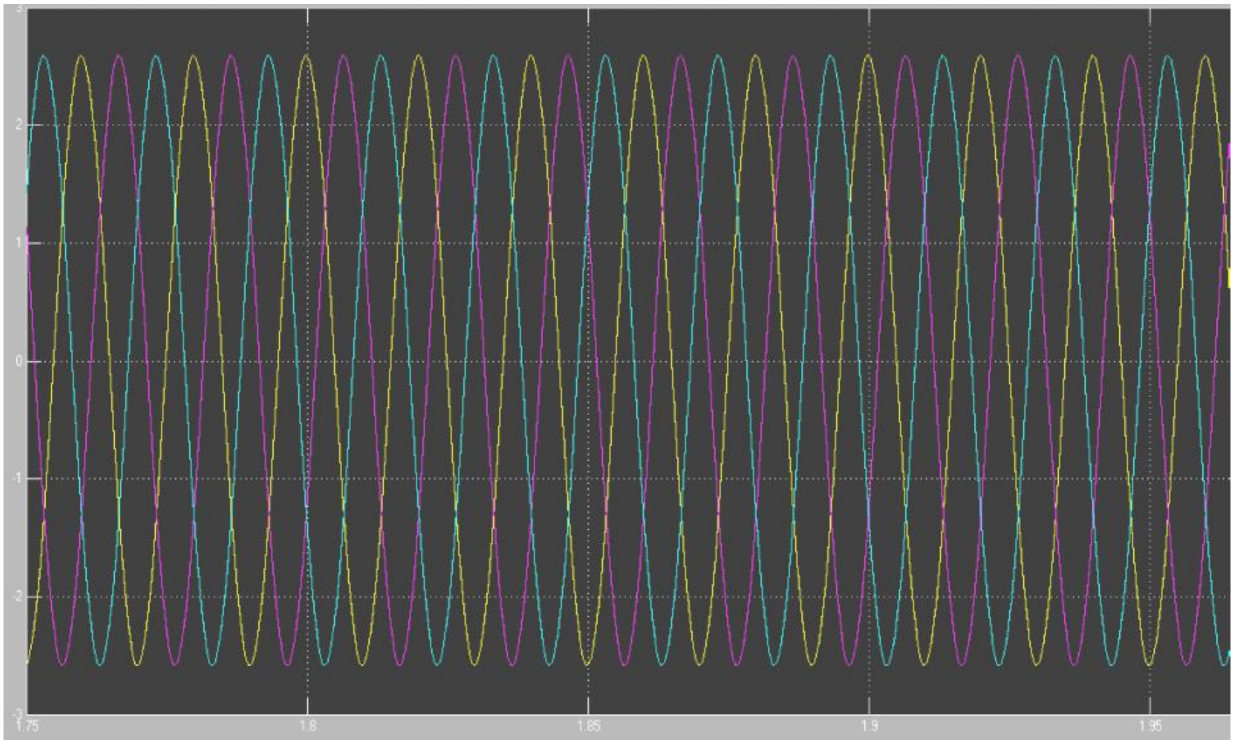


Figure 13: THD for Source Current Before Compensation

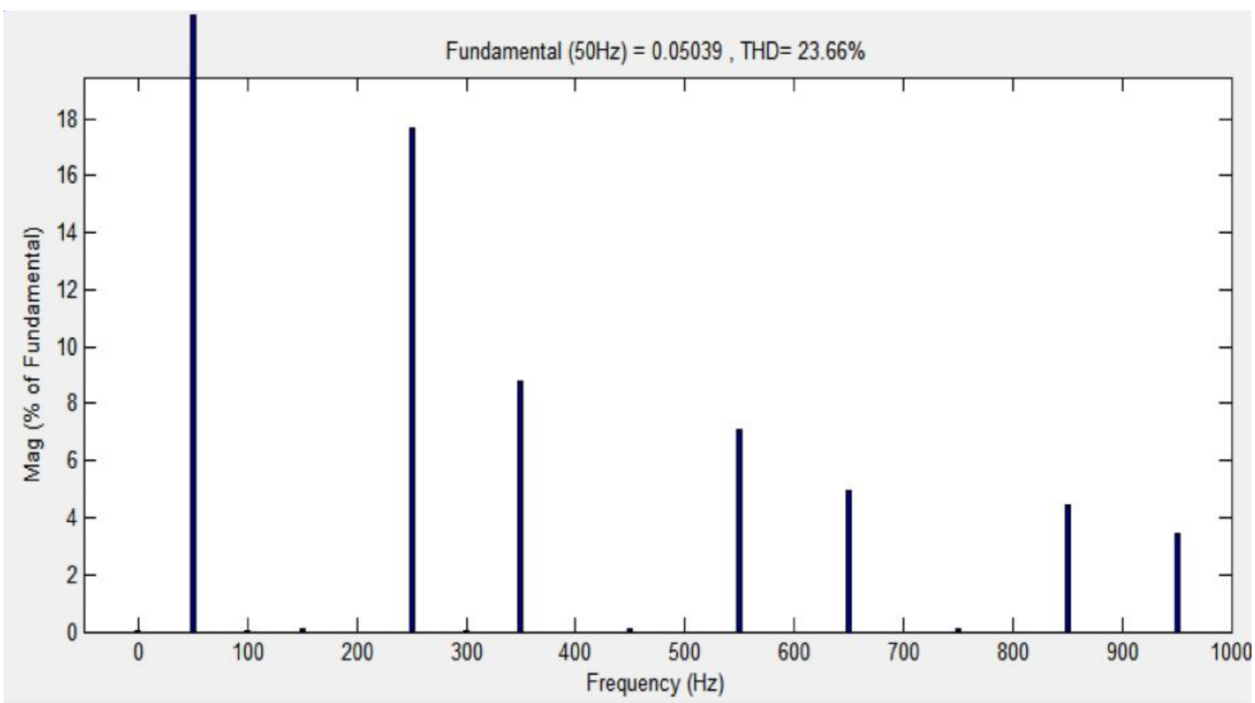
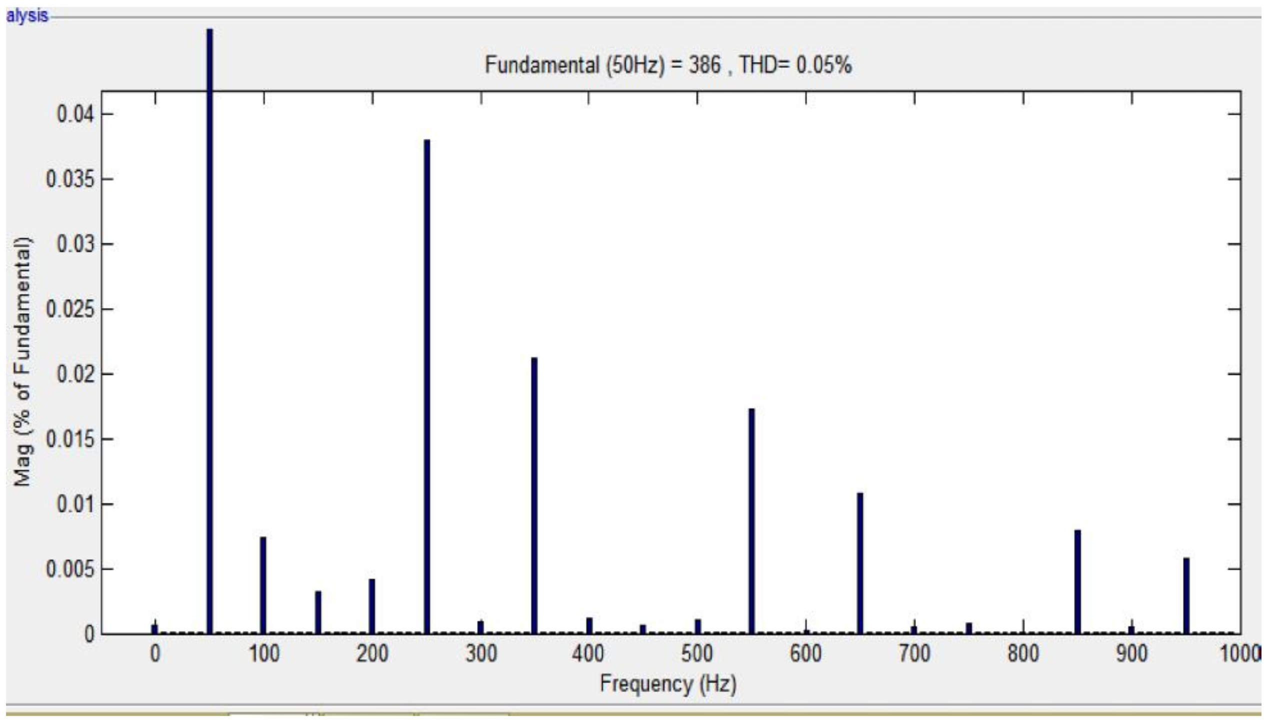


Figure 14: THD for Source Current Before Compensation



Tabular Column 1: Comparison of THD Between with and Without UPQC

	Without UPQC		With UPQC	
	VALUES	**THD%**	**VALUES**	**THD%**
I source	0.045 A	23.66	2.45 A	0.55
V source	360 V	0.79	360 V	0.05
I load	3.5*10^-4 A	0.8	2.45 A	0.61
V load	360 V	0.91	360 V	0.31

The tabular column shown below indicates the difference in the system having UPQC and without UPQC.

CONCLUSION

This paper has dealt with UPQC's, the aim of which is not only to compensate for current harmonics produced by nonlinear loads, but also to eliminate voltage flicker/imbalance appearing at the receiving terminal from the load terminal. Theoretical comparison among three types of control methods for the series-active filter has clarified that the combination of current and voltage-detecting methods is suitable for voltage flicker/imbalance elimination and harmonic compensation. The flow of instantaneous active and reactive powers has shown that installation of the shunt-active filter is effective in performing dc-voltage regulation.

The proposed control strategy use only minimum measurement like loads and mains voltage measurements for series APF based on the modified PLL with synchronous reference frame theory. The instantaneous reactive power theory is used for shunt APF control algorithm by measuring mains voltage, currents and capacitor voltage. But the conventional methods require measurements of the load, source and filter voltages and currents. The simulation results show that, when unbalanced and Nonlinear load current or unbalanced and distorted mains voltage conditions, the above control algorithms eliminate the impact of distortion and unbalance of load current on the power line, making the power factor unity. 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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