Unified Power Quality Conditioner (UPQC)-An Extensive Review

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Abstract: The term active power filter (APF) is a widely used terminology in the area of electric power quality improvement. APFs have made it possible to mitigate some of the major power quality problems effectively. This work focuses on a Unified Power Quality Conditioner (UPQC). The UPQC is one of the APF family members where shunt and series APF functionalities are integrated together to achieve superior control over several power quality problems simultaneously. There are two important types of APF, namely, shunt APF and series APF. The shunt APF is the most promising to tackle the current-related problems, whereas, the series APF is the most suitable to overcome the voltage-related problems. This paper presents an extensive review of Unified Power Quality Conditioner and the control strategies used for compensation of power quality problems.

Keywords: **Power quality, Active Pass filter, Unified Power Quality Conditioner (UPQC), STATCOM, DVR, Park's Transformations**

I. Introduction

It has been always a challenge to maintain the quality of electric power within the acceptable limits. Some of the adverse effects of poor power quality may result into increased power losses, abnormal and undesirable behaviour of equipments, interference with nearby communication lines, and so forth. The widespread use of power electronic based systems has further put the burden on power system by generating harmonics in voltages and currents along with increased reactive current. The term active power filter (APF) is a widely used terminology in the area of electric power quality improvement. APFs have made it possible to mitigate some of the major power quality problems effectively. This work focuses on a Unified Power Quality Conditioner (UPQC) and its performance analysis.

The UPQC is one of the APF family members where shunt and series APF functionalities are integrated together to achieve superior control over several power quality problems simultaneously. There are two important types of APF, namely, shunt APF and series APF. The shunt APF is the most promising to tackle the current-related problems, whereas, the series APF is the most suitable to overcome the voltage-related problems. Since the modern distribution system demands a better quality of voltage being supplied and current drawn, installation of these APFs has great scope in actual practical implementation. However, installing two separate devices to compensate voltage-and current-related power quality problems, independently, may not be a cost effective solution. Akagi described a system configuration in which both series and shunt APFs were connected back to back with a common dc reactor [1]. The topology was addressed as line voltage regulator/conditioner. The back-to-back inverter system configuration truly came into attention when Fujita and Akagi proved the practical application of this topology with 20 kVA experimental results [2]. They named this device as Unified Power Quality Conditioner (UPQC), and since then the name UPQC has been popularly used by majority of the researchers.

 DOI : 10.18231/2454-9150.2018.1153

ISSN : 2454-9150 Vol-04, Issue-09, Dec 2018

II. UNIFIED POWER QUALITY CONDITIONER

The Unified Power Quality Conditioner (UPQC) is quite similar to Unified Power Flow Controller (UPFC), although they differ from each other in the fact that UPQC is used for compensation in distribution system whereas UPFC is used in the transmission system. As the transmission system generally remains balanced and harmonic free, the UPFC does not provide compensation for harmonics and unbalance while UPQC operates in distribution system where unbalance and harmonics normally occurs. The UPQC not only compensates for voltage sag but also ensures that the harmonic current drawn by the non linear load does not reach to the source. It does that by injecting required amount of harmonic current exclusive from reactive power compensation.

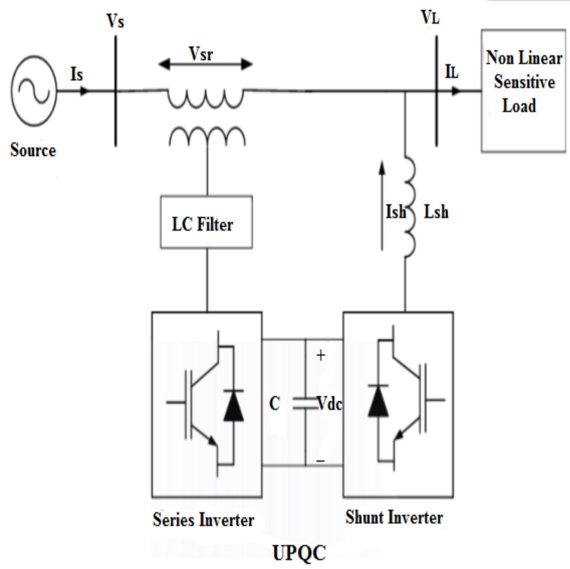


Fig.1.1 Block diagram of UPQC system [1]

The UPQC encompasses of two voltage source inverters (VSI) connected through a common dc bus consisting a capacitor. One inverter, connected in shunt through inductor coupling is known as Shunt Active Pass Filter (APF) or STATCOM that compensates for the harmonic and reactive current taken by the load and hence making the source current to be in phase with the source voltage and sinusoidal. Other inverter is connected in series through series transformer known as Series Active Pass Filter or Dynamic Voltage Restorer (DVR) that injects a voltage in case of sag or swell in the source voltage for maintaining the load end voltage at its normal value. The integration of both series active filters and shunt active filters helps in optimizing the performance whereas independent functioning is neither optimal nor cost effective [1].

Shunt APF

The shunt inverter in UPQC is controlled in current controlled mode such that it delivers a current which is equal to the set value of the reference current as governed by UPQC control algorithm. Additionally, the shunt inverter plays an important role in achieving required performance from UPQC system by maintaining the dc bus voltage at a set reference value.

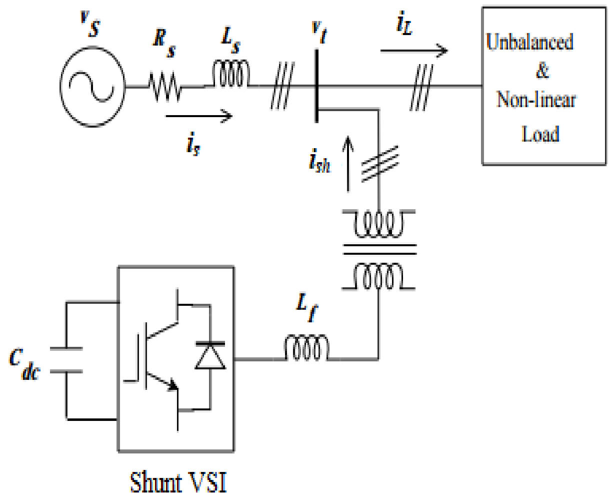


Fig.1.2Block diagram of Shunt APF system [34]

In order to cancel the harmonics generated by a nonlinear load, the shunt inverter should inject a current as governed by following equation

$$i_{sh} = i_s - i_L \qquad (1.1)$$

Where i_{sh}, i_s, i_L represent the shunt inverter current, reference source current, and load current, respectively. The compensation of load current harmonics is done by injecting an equal and opposite harmonics compensating current through shunt inverter of UPQC. It operates as a current source injecting the harmonic components generated by the load but phase shifted by 180^0 . The shunt active filter has to supply all the reactive and harmonics power demand of load and at the same time, it will draw real component of power from the utility to supply switching losses and to maintain the dc link voltage unchanged [6],[7],[8],[9].

DOI : 10.18231/2454-9150.2018.1153

Series APF

The series inverter of UPQC is controlled such that it generates a voltage and injects in series with line to achieve a sinusoidal, free from distortion and at a desired magnitude voltage at the load terminal.

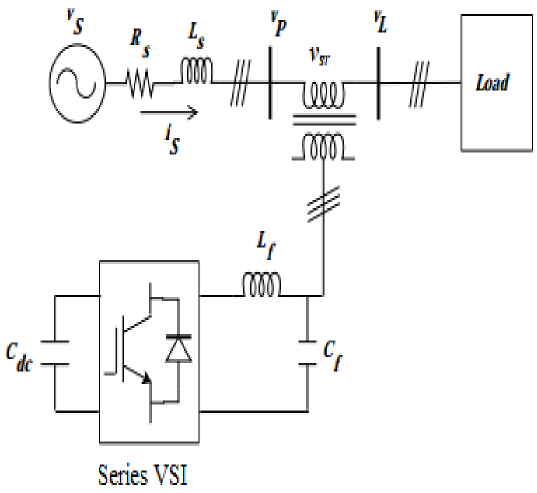


Fig.1.3 Block diagram of Series APF system [34]

The operation of a series inverter in UPQC can be understood by following equation

$$v_{sr} = v_s - v_L \qquad (1.2)$$

Where v_{sr} ,v_s, v_L represents the series inverter injected voltage, reference load voltage, and actual source voltage, respectively. In the case of a voltage sag condition, v_{sr} will represent the difference between the reference load voltage and reduced supply voltage, i.e., the injected voltage by the series inverter to maintain voltage at the load terminal at reference value. In UPQC, the shunt inverter is operated as controlled current source and the series inverter as controlled voltage source except [19] in which the operation of series and shunt inverters is interchanged. In shunt APF the reference quantity is source current while in the series APF, the reference quantity is load voltage. A series compensator is the dual of a shunt compensator as it protects a sensitive load from the distortion in the supply side voltage.

The basic principle of a series compensator is to insert a voltage of required magnitude and frequency. It restores the load side voltage to the desired amplitude and waveform even when the source voltage is unbalanced or distorted. The series compensator or DVR is capable of generating or absorbing independently controllable real and reactive power at its ac output terminal. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the DVR and the distribution system. The dc input terminal of a DVR is connected to an energy source or an energy storage device of appropriate capacity. The reactive power exchanged between the DVR and the distribution system is internally generated by the DVR without ac passive reactive components. The real power exchanged at the DVR output ac terminals is provided by the DVR input dc terminal by an external energy source or energy storage system [10],[11]. The voltage sag can be considered to be the important power quality problem and so will be paid a special attention in UPQC. The UPQC system can be classified in a way the series filter or DVR used to mitigates the voltage [12]. Some basic methods will be discussed in the next section.

.UPQC-P

In UPQC-P (P for active power), active power is used to mitigate the voltage sag. In UPQC-P, an in-phase voltage component is injected in the series with line through a series inverter to compensate the voltage sag [13],[14],[15],[16],[17]. This in-phase component is equal to reduced voltage magnitude from the desired load voltage value. To achieve the effective sag compensation, the shunt inverter of UPQC draws the necessary active power required by the series inverter including the losses associated with UPQC. Due to this, an increased source current magnitude during voltage sag compensation in.

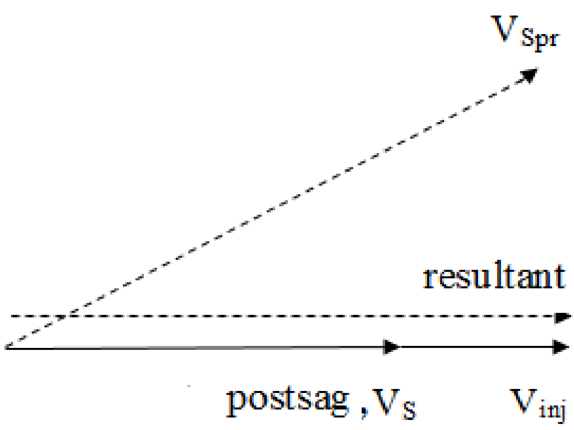


Fig.1.4 Phasor diagram of UPQC-P [13]

 DOI : 10.18231/2454-9150.2018.1153

ISSN : 2454-9150 Vol-04, Issue-09, Dec 2018

UPQC-P can be observed. The UPQC-P can be analyzed for minimum voltage injection of DVR in either of voltage sag or swell.

UPQC-Q

The voltage sag can also be mitigated by injecting reactive power through the series inverter of UPQC and hence called as UPQC-Q (Q for reactive power) [21],[22]. The concept is to inject a quadrature voltage through the series inverter of UPQC such that the vector sum of source voltage and the injected voltage equals the required rated voltage at the load bus terminal but phase shifted with respect to the source voltage. Therefore, by injecting the series inverter voltage in quadrature with the source voltage, the need of active power to compensate the sag on the system is eliminated. The shunt inverter of UPQC necessarily maintains a unity power factor operation at the source side. The UPQC-Q requires larger magnitude of series injection voltage than the UPQC-P so as the required rating of series inverter in UPQC-Q is increased. In UPQC-Q, the DVR can not mitigate for voltage swell. This mode of UPQC is orthodox and provides minimum level of compensation. Among the two approaches, the UPQC-P is the most commonly used method for voltage sag compensation in UPQC applications because the UPQC-Q cannot mitigate the voltage swell on the system.

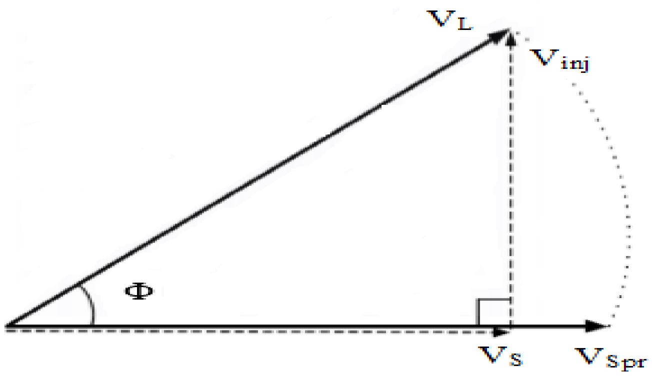


Fig.1.5 Phasor diagram of UPQC-Q [21]

UPQC-VAmin

There has been always a scope to minimize the UPQC VA (Volt-Amperes) loading during voltage sag compensation. Instead of injecting the series voltage in quadrature or in-phase, it can also be is injected at an optimal angle with respect to the source current. This method to compensate the voltage sag using UPQC is abbreviated as UPQC-VA*min* [23],[24]. Beside the series voltage injection, the current drawn by the shunt inverter to maintain dc bus and overall power balance needs to be taken into account while determining the minimum VA loading of UPQC. A comparison on VA loading to mitigate voltage sag using UPQC-P, UPQC-Q, and UPQC-VA*min* methods is carried out in [23].

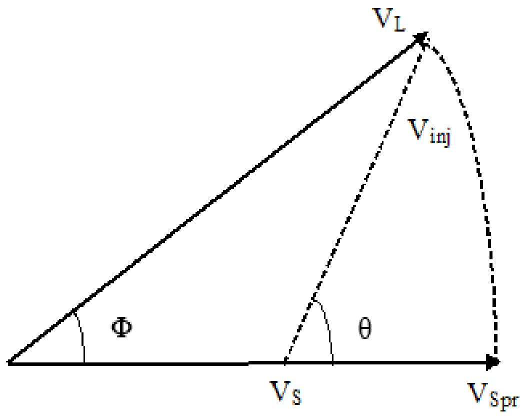


Fig.1.6 Phasor diagram of UPQC-*VAmin* [23]

UPQC-S

The UPQC-S is similar to UPQC-*VAmin*, where the series inverter delivers both active and reactive power and hence it is given the name UPQC-S (S for complex power) [25]. Unlike the UPQC-*VAmin*, in this method, the efforts are made to utilize the available series inverter VA loading to its maximum value. The series inverter of UPQC performs simultaneous voltage sag/swell compensation and load reactive power sharing with the shunt inverter. The control of UPQC-S involves several control loops and, thus, appears relatively complex to employ [35]. Both UPQC-*VAmin* and UPQC-S, suggest a new era for development in the subject of power quality enhancement using UPQC where the series inverter of UPQC is being used optimally.

DC Link Capacitor

The control of dc link voltage plays an important role in achieving the desired UPQC performance during the system dynamic conditions, the dc link feedback controller should respond as fast as possible to restore the dc link voltage at a set reference value, with minimum delay as well as lower overshoot. The reactive power compensation of a balanced and linear load can however be achieved without energy storage element such as capacitors but in an unbalanced and nonlinear load (harmonic current), the compensation must

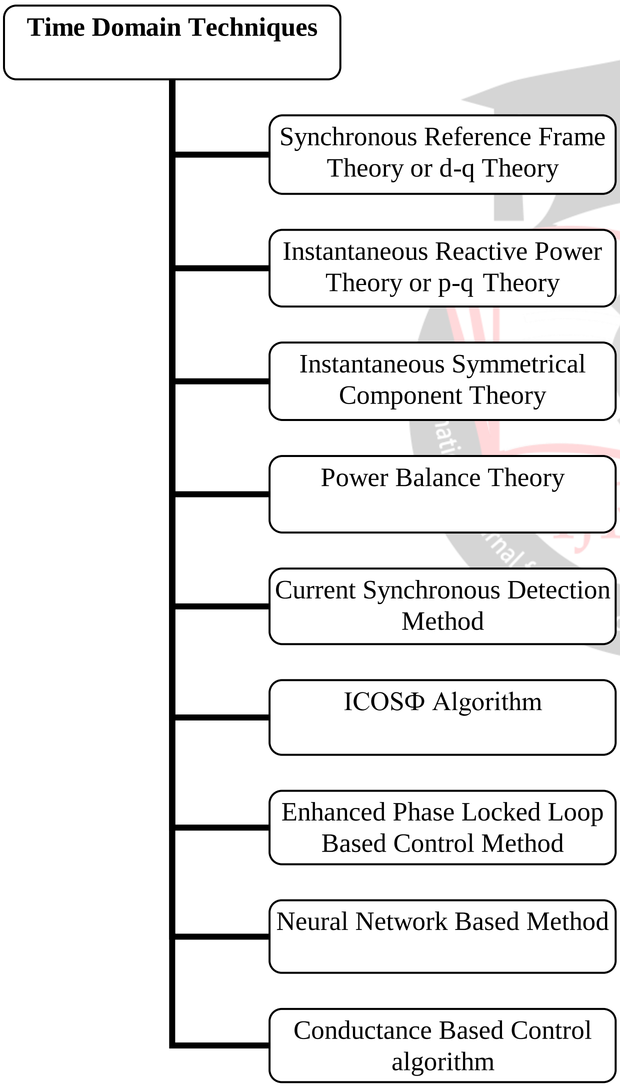
 DOI : 10.18231/2454-9150.2018.1153

ISSN : 2454-9150 Vol-04, Issue-09, Dec 2018

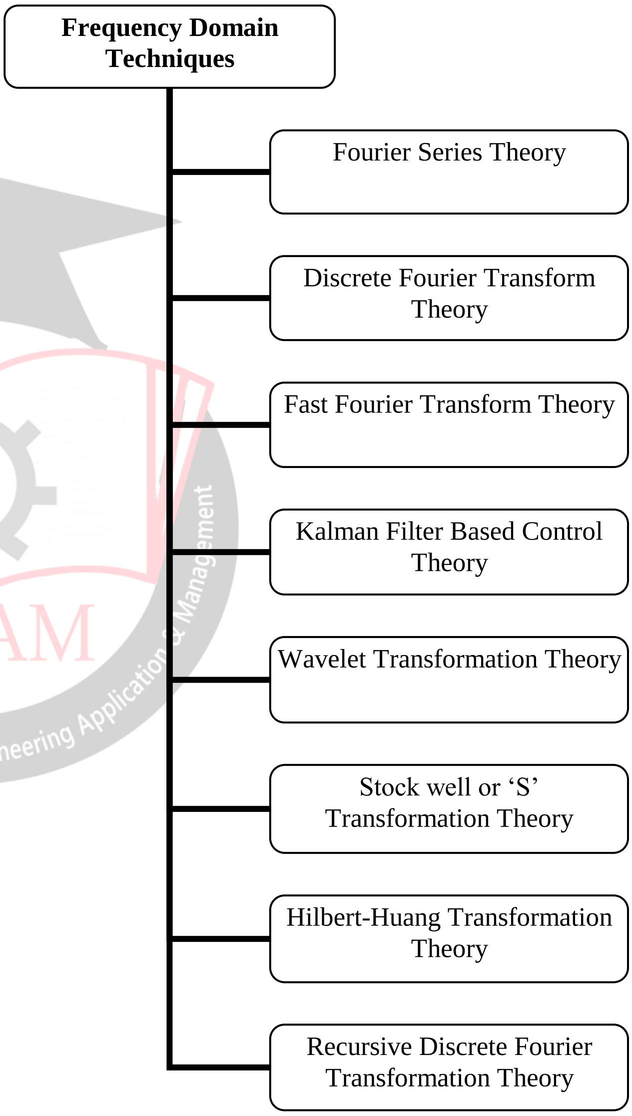
requires energy storage elements. The proportional-integral (PI) regulator based dc link voltage controller is simple to implement and hence most widely used. Although it suffers from a disadvantage of relatively slower response.

III. CONTROL TECHNIQUES

The reference signal generation is the most important part of the control techniques used for UPQC as the filter performance completely depends upon the accuracy of reference signal generation. As UPQC provides compensation for harmonics in both current and voltage, the control techniques which require harmonics extraction can be classified as time domain control techniques and frequency domain control techniques.



The frequency domain control techniques are computationally extensive, basically based on Fast Fourier Transform (FFT). In this method, the FFT for one cycle of input signal is performed for extracting the magnitude and phase information of each components of frequency and thus causing delay in compensation. The fundamental frequency term is removed by setting the frequency component to 0-50Hz and taking inverse Fourier Transform and introducing time delays. The change in load current causes distortion in the waveform of signal which results error in output of FFT due to which the incorrect compensating signal is generated. Although this can be avoided by another control algorithm which detects change in load current and generates zero compensating signal for one cycle. The frequency domain control techniques have advantage to perform selective harmonic cancellation [27].



. The most common control techniques in time domain are the one based on synchronously rotating reference frame (SRF) or d-q theory [18],[19],[20],[21] and other on instantaneous active and reactive power or p-q theory [12],[13],[14],[15],16].

 DOI : 10.18231/2454-9150.2018.1153

Both these methods employ Park's Transformation. The instantaneous active reactive power theory employs Park's transform to calculate instantaneous active and reactive power. Both these theories transform the fundamental quantities into dc quantities and the oscillating component represent the harmonic content which is extracted by Low pass or High pass filter. Harmonic current represents the ripple component in both the powers while the dc component represents the fundamental power. This method has the advantage of simple arithmetic operations with terminal measurement. The Synchronous Rotating Frame method also uses Park's Transform but needs a Phased Locked Loop (PLL) [18].

Some methods that do not require harmonic extraction make use of hysteresis control by multiplying the control output with reference sine template and forcing the feedback signal to follow reference signal using hysteresis control [17]. The disadvantage of methods involving hysteresis control is that the switching frequency is variable and hence the converter is difficult to design. There are various control techniques that have been employed for the control of UPQC system such as fuzzy control and sliding mode control [12], scalar or unit vector template generation[15], particle swarm optimization [24] etc.

IV. CONCLUSION

The various researchers have used various topologies for connecting series and shunt active filters of the UPQC and techniques to control the operation as well as for reference generation.

Performance Metrics	% of Voltage Sag	THD For Voltage	THD For Current
Without UPQC	49.87%	11.37%	19.62%
With UPQC	15.66%	3.61%	3.59%

Table1.1 A comparison of performance with UPQC and without UPQC

This paper presents an extensive survey related to UPQC and power quality and the basic ideas related to them as well as the review and comparison of various control techniques. The Power quality is an important issue and needs to be addressed and the UPQC is found to be the best solution. The Total Harmonic Distortion is an important parameter of measuring the distortion in power quality .The table1.1 shows how helpful is the UPQC in improving the THD and voltage sag/swell [20].

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