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UPQC System With an Improved Control Method Under Distorted and Unbalanced Load Condition

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Abstract:-In order to improve the power quality at the distribution side the unified power quality conditioner has become the most attractive solution. The unified power quality conditioner(UPQC) is consisting of both the series and shunt active power filters such that it can improve power quality both on the source side as well as on the load side. In this paper simplified control techniques have been described for controlling the shunt and series active power filters. For controlling the shunt active power filter two methods are analysed and the series active power filter is controlled by synchronous reference frame theory using three phase locked loop (PLL). The model for the control techniques of both the shunt and series active power filters have been presented.

Keywords:-Unified Power Quality Conditioner (UPQC), Active Power Filter(APF), Phase Locked Loop(PLL), Power Quality(PQ).

[I] INTRODUCTION

The unified power quality conditioner (UPQC) is one of the most preferable custom power device which can mitigate both voltage and current related power quality issues in the distribution system. The voltage related issues are mitigated by using series active power filter while the current related issues are cleared by using the shunt APF. As due to the nonlinear and distorted unbalanced load at the distribution side the power quality at the distribution side is getting poor day by day. Hence, in order to mitigate the harmonics introduced from the load side of the distribution system these active power filters plays a significant role. The voltage sags ,swells, harmonics, flickers all these voltage related problems are mitigated by using series APF with the three phase locked loop. While to eliminate current harmonics and improve power factor at the load side shunt APF is used. Hence, UPQC is one of the most commonly used custom power device which is capable to improve the power quality not only on the load side but also on the source side simultaneously with the reactive power compensation.

There are many control strategies to control the active power filters. This paper is presenting simplified method for controlling the shunt APF using the Constant Power Control Technique and the Synchronous Reference Frame Theory. While the series APF is being controlled by using simple Synchronous Reference Frame Theory with the help of three phase locked loop (PLL).

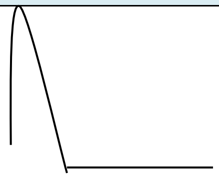
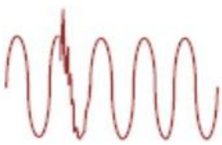
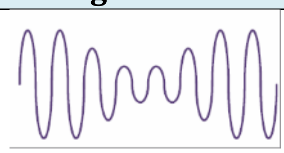
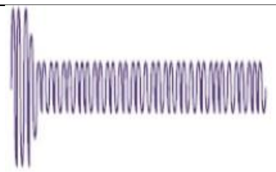
[II] Power Quality issues with their causes and effects

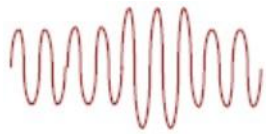
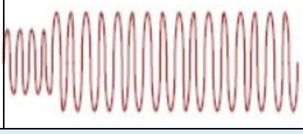
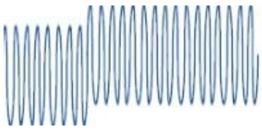
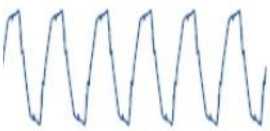
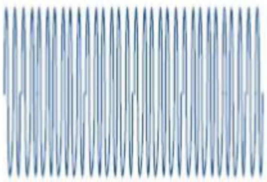
Power Quality is surely an important concern in most industries today, because of the increase in the number of load sensitive to power disturbances. The power quality is an index to quality of current and voltage available to industrial, commercial and household consumers of electricity. The problem regards both the utilities and customers. For the utilities, to provide adequate power quality is a moving objective because of changes in user equipment and requirements.

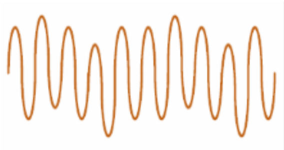
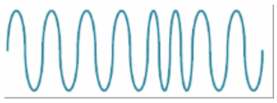
Power quality is a topic embracing a large field. On one side, several different events are involved in power quality: spikes or surges, sags, swells, outages, under and over voltages, harmonics, flicker, frequency deviations, and electrical noise.

Voltage sag in electrical grid are not always possible to avoid because of finite clearing time of faults that cause the voltage sag. Voltage sag are the common reason for interruption in production plants and for end user equipment malfunctions in general. In particular, tripping of equipment in a production line can cause production interruption and significant costs due to loss of production.

Table 1. Summary of Disturbances with Solutions

Disturbanc e Category	Wave Form	Effects	Possible Causes	Possible Solutions
1.Transients				
Impulsive		Loss of data, possible damage, system halts	Lightning, ESD, switching impulses, utility fault clearing	TVSS, maintain humidity between 35-50%
Oscillatory		Loss of data, possible damage	Switching off inductive/ Capacitive Loads	TVSS, UPS, Reactors/Choke s, Zero Crossing Switch
2.Interruptions				
		Loss of data, possible damage, shutdown	Switching, utility faults, CB tripping, component failures	UPS, DVR
3. Sag / Under voltage				
Sag		System halts, loss of data, shutdown	Startup loads, faults	UPS, DVR
Under Voltage		System halts, loss of data, shutdown	Utility faults, load changes	UPS, DVR

4. Swell / Overvoltage				
Swell		Nuisance tripping, Equipment damage/ reduced Life	Load changes, utility faults	DVR , UPS, Ferro resonant control Transformers
Overvoltage		equipment damage/reduced life	Load changes, utility faults	DVR ,UPS, Ferro resonant control Transformers
5. Waveform Distortion				
DC Offset		Transformers heated, ground fault current, nuisance tripping	Faulty rectifiers, power supplies	Troubleshoot and replace defective equipmen t
Harmonics		Transformer s heated, System halts	Electronic loads (non-linear loads)	Reconfigure distribution , install k-factor transformers
Inter harmonics		light flicker, heating, communicatio n interference	faulty equipment Cyclo converter freq. converters, induction motor arcing devices	Power Conditioner, Filters, UPS
Notching		System halts, data loss	Variable speed drives, arc welders, light dimmers	Reconfigure distribution, relocate sensitive loads, install filters, UPS
Noise		System halts, data loss	Transmitters (radio), faulty equipment, ineffective grounding	Remove transmitters, reconfigure grounding, increase shielding, filters

6.Voltage Fluctuations				
		System halts, light flicker	Intermittent operation of load equipment	Reconfigure distribution, Relocate sensitive loads, UPS
7. Power Frequency Variations				
		Synchronous equipment failure, No effect on IT equipment	Standby generators ineffectivel y governed	Upgrade generato rgovern or

[III]Control Strategies for Active Power Filters

A.Shunt Active Power Filter

The SAPF technology is now a mature technology for providing harmonic current compensation, reactive power compensation, and neutral current compensation in AC distribution networks. It has evolved in the past quarter century with development in terms of varying configurations, control strategies, and solid-state devices. Shunt active power filters are also used to regulate the terminal voltage and suppress voltage flicker in three-phase systems. These objectives are achieved either individually or in combination depending upon the requirements, control strategy, and configuration that need to be selected appropriately. Shunt active power filter is considered as an ideal device for mitigating power quality problems. The shunt active power filters are basically categorized into three types, namely, single-phase two-wire, three-phase three-wire, and three-phase four-wire configurations, to meet the requirements of the three types of nonlinear loads on supply systems. Some single-phase loads such as domestic lights, ovens, TVs, computer power supplies, air conditioners, laser printers, and Xerox machines behave as nonlinear loads and cause power quality problems. Single-phase two-wire active power filters of varying configurations and control strategies have been investigated to meet the needs of single-phase nonlinear loads. Starting from 1971, many configurations of shunt active power filters have been developed and commercialized in UPS applications. Both current source converter with inductive energy storage and voltage source converter with capacitive energy storage are used to develop single-phase SAPFs. A major amount of AC power is consumed by three-phase loads such as ASDs with solid-state control and lately in the front-end design of many other electrical loads the active power filters have been incorporated. A substantial work has been reported on three-phase, three-wire APFs. Starting from 1976, many control strategies such as instantaneous reactive power theory (IRPT), synchronous frame d–q theory, synchronous detection method, notch filter method are used in the development of three-phase APFs. The problem of excessive neutral current is observed in three-phase four-wire systems mainly due to nonlinear unbalanced loads such as computer power supplies, fluorescent lighting, and so on. These problems of neutral current and unbalanced load currents in four-wire systems have been attempted to resolve through elimination/ reduction of neutral current, harmonic compensation, load balancing, and reactive power compensation.

Principle of Operation of Shunt Active Power Filters :-The main objective of shunt active power filters is to mitigate multiple power quality problems in a distribution system. SAPF mitigates most of the current quality problems, such as reactive power, unbalanced currents, neutral current, harmonics, and fluctuations, present in the consumer loads or otherwise in the system and provides sinusoidal balanced currents in the supply along with its DC bus voltage control. In general, a SAPF has a VSC connected to a DC bus and its AC side is connected in shunt normally across the consumer loads or across the PCC, as shown in Figure 1. The VSC uses PWM current control; therefore, it requires small ripple filters to mitigate switching ripples. It requires Hall effect voltage and current sensors for feedback signals and normally a digital signal processor (DSP) is used to implement the required control algorithm to generate gating signals for the solid-state devices of the VSC of the SAPF. The VSC used as SAPF is normally controlled in PWM current control mode to inject appropriate currents into the system. The SAPF also needs many passive elements such as a DC bus capacitor, AC interacting inductors, and small passive filters.

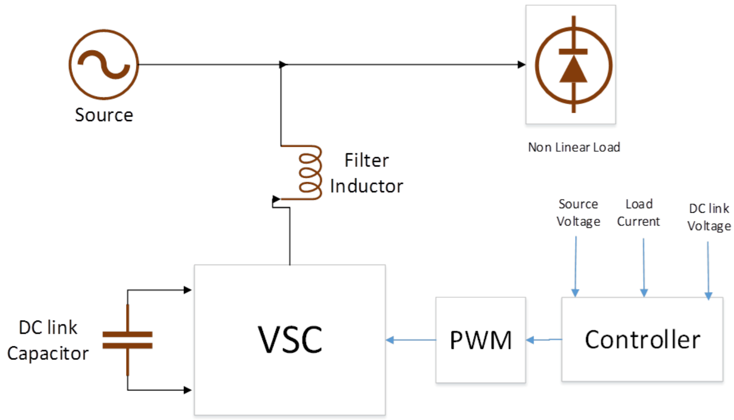


Fig.1:-Shunt Active Power Filter

Control of Shunt Active Power Filter:- Reference current signals for the control of SAPF have to be derived accordingly and these signals may be estimated using a number of control algorithms. There are many control algorithms available for the control of SAPFs. In this paper two control strategies are discussed.

i)Constant Power Control Technique

ii)Synchronous Reference Frame Theory

Constant Power Control Technique

Clark Transformation : abc to αβ

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & \sqrt{3/2} & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Inverse Clark Transformation : αβ to abc

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -0.5 & \sqrt{3/2} \\ -0.5 & -\sqrt{3/2} \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Based on instantaneous p-q theory

$$p = v_\alpha i_\alpha + v_\beta i_\beta$$
$$q = v_\beta i_\alpha - v_\alpha i_\beta$$

Instantaneous Active Power, $p = \tilde{p} + \bar{p}$

Instantaneous Reactive Power $q = \tilde{q} + \bar{q}$

Reference Current

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} p_{loss} - \tilde{p} \\ -q \end{bmatrix}$$

p_{loss} = Power loss in VSC and Required power to Charge Capacitor

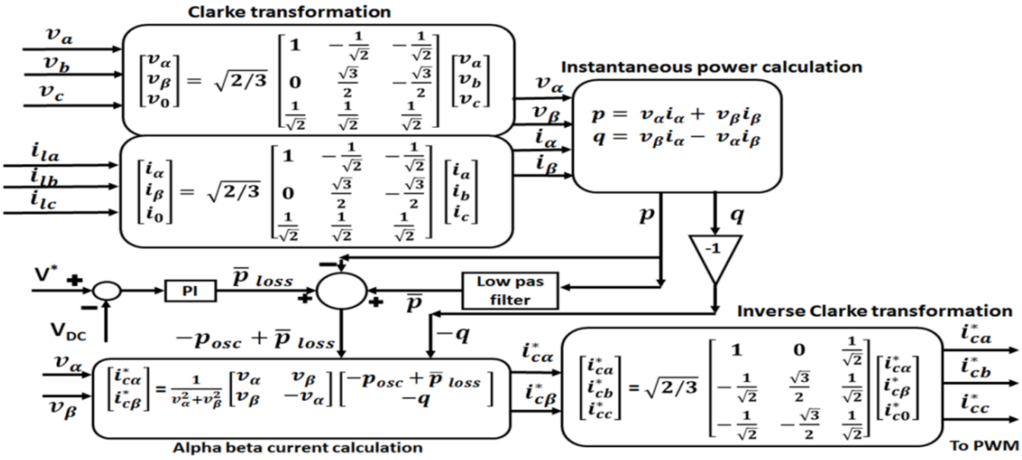


Fig.2:-SAPF using Constant Power Control Technique

Synchronous Reference Frame Theory

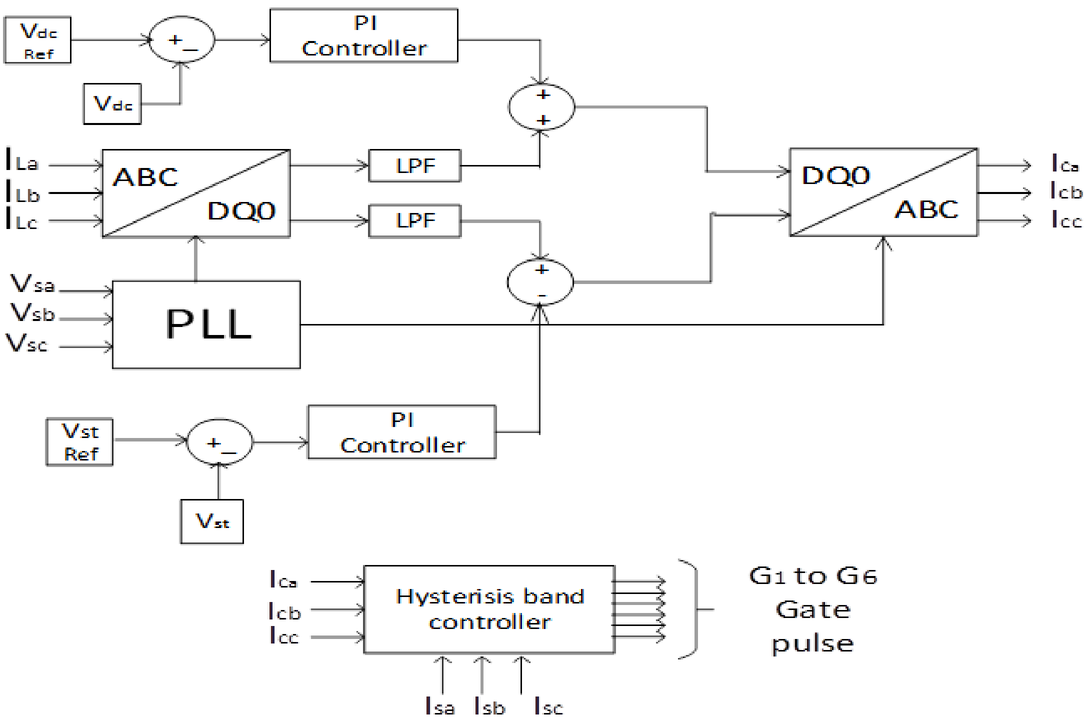


Fig.3:-SAPF using Synchronous Reference Frame Theory

B. Series Active Power Filter

Among the power quality problems (sags, swells, harmonics…) voltage sags are the most severe disturbances. In order to overcome these problems the concept of custom power devices is introduced recently. One of those devices is the series APF, which is the most efficient and effective modern custom power device used in power distribution networks. It is generally connected where sensitive loads are present at the load side.

A power electronic converter based series compensator that can protect critical loads from all supply side disturbances other than outages is called a series APF. It injects a set of three phase AC output voltages in series and synchronism with the distribution feeder voltages. The amplitude and phase angle of the injected voltages are variable thereby allowing control of the real and reactive power exchange between the device and the distribution system.

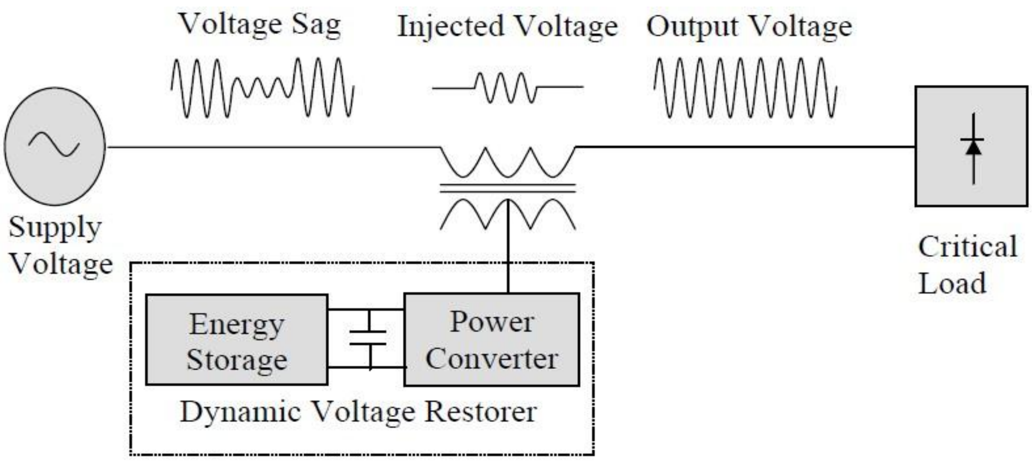


Fig.4:-Series Active Power Filter

BASIC Series APF OPERATING PRINCIPLE

The series APF is operated by injecting three phase AC voltages in series with the three phase incoming network voltages during a sag, compensating for the difference between faulty and nominal voltages. All three phases of the injected voltages are of controllable amplitude and phase.

Voltage source inverters (VSI) fed from a DC link and supply the active and reactive power. Harmonics produced by the operation of VSI must be reduced to an acceptable limit fined by proper filtering scheme. VSI switches an impact on the harmonics produced. The required energy during sags has to be supplied by an energy source. The necessary amount of energy that must be delivered by the energy source depends on load MVA requirement, control strategy applied, deepest sag to be protected.

Control of Series APF:-The control of series active power filter is achieved by using simple Synchronous reference frame theory with the battery aided support system as shown in the fig.5 given below.

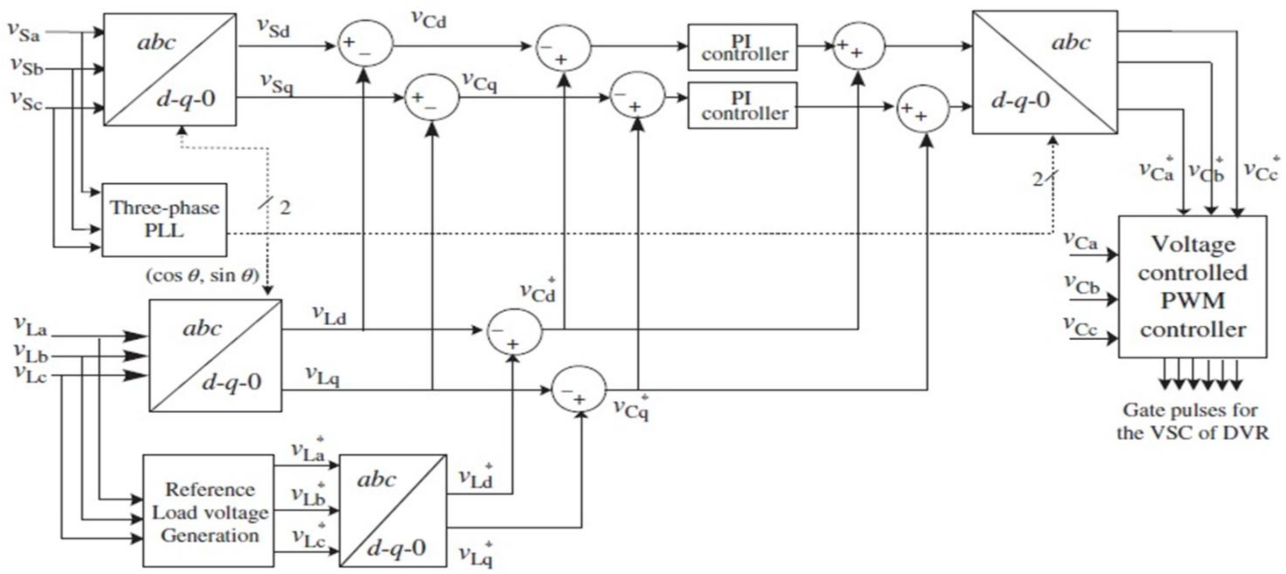


Fig.5:-Series APF using Synchronous Reference Frame Theory

Conclusion:-The proposed control techniques have been used to control both the shunt and series APF'S with the minimum measurements like load current and source voltages. The paper describes the basic principle of the control strategies. With these control strategies both the active power filters are able to mitigate voltage distortion and current harmonics on both the load as well as source side simultaneously with the reactive power compensation.

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