Mitigation of Harmonics in Distribution System Using SAPF

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ABSTRACT: *The typical loads in the commercial buildings comprise of many single phase and three phase loads which includes non-linear loads. These loads are highly sensitive for any input variations in voltage. The performance of the electrical equipment gets worsened if they are supplied with polluted or distorted voltage. This paper presents modeling and analysis of custom power devices. SAPF based UPQC to take power quality problems. Series active power filter is implemented for harmonic and voltage distribution compensation of the three phase three wire distribution system. The custom power devices are realized by the hysteresis control based SAPF .The SAPF can be realized by three phase three leg VSI .A dynamic model of SAPF is developed in the MATLAB/SIMULINK environment and the simulation results are presented to show the effectiveness of proposed SAPF custom power device for a three phase three wire distribution system.*

Keywords: *Custom Power Devices, Hysteresis Based Controller, MATLAB, SAPF (Series Active Power Filter), SIMULINK, UPQC (Unified Power Quality Conditioner),VSI(Voltage Source Inverter).*

I. INTRODUCTION

Power quality phenomena include all possible situations in which the waveform of the supply voltage (voltage quality) or load current (current quality) deviate from the sinusoidal waveform at rated frequency with amplitude corresponding to the rated rms value for all three phases of a three-phase system[1]. The wide range of power quality disturbances covers sudden, short duration variations, e.g. impulsive and oscillatory transients, voltage sags, short interruptions, as well as steady state deviations, such as harmonics and flicker. One can also distinguish, based on the cause, between disturbances related to the quality of the supply voltage and those related to the quality of the current taken by the load [2].To the first class covers voltage dips and interruptions, mostly caused by faults in the power system. These disturbances may cause tripping of "sensitive" electronic equipment with disasters us consequences in industrial plants where tripping of critical equipment can bear the stoppage of the whole production with high costs associated. One can say that in this case it is the source that disturbs the load. To avoid consistent money losses, industrial customers often decide to install mitigation equipment to protect their plants from such disturbances. The second class covers phenomena due to low quality of the current drawn by the load. In this case, it is the load that disturbs the source. A typical example is current harmonics drawn by disturbing loads like diode rectifiers, or unbalanced currents drawn by un balanced any direct production loss related to the occurrence of these power quality phenomena. But poor quality of the current taken by many customers together will ultimately result in low quality of the power delivered to other customers[3]. Both harmonics and unbalanced currents ultimately cause distortion and respectively, unbalance in the voltage as well. Therefore, proper standards are issued to limit the quantity of harmonic currents, unbalance and/or flicker that a load may introduce. To comply with limits set by standards, customers often have to install mitigation equipment .In recent years, both industrial and commercial customers of utilities have reported a rising tide of misadventures related to power quality. The trouble stems from the increased refinement of today's automated equipment, whether variable speed drives or robots, automated production lines or machine tools, programmable logic controllers or power supplies in computers. They and their like are far vulnerable to disturbances on the

utility system than were the previous generation of electromechanical equipment and the previous less automated production and information systems. A growing number of loads is sensitive to customers' critical processes which have costly consequences if disturbed by either poor power quality or power interruption.For the reasons described above, there is a growing interest in equipment for mitigation of power quality disturbances, especially in newer devices based on power electronics called "custom power devices" able to deliver customized solutions to power quality problems. The term Custom Power describes the value-added power that electric utilities and other service providers will offer their customers in the future. The improved level of reliability of this power, in terms of reduced interruptions and less variation, will stem from an integrated solution to present problems, of which a prominent feature will be the application of power electronic controllers to the utility distribution systems and/or at the supply and of many industrial and commercial customers and industrial parks.The compensating devices are used for active filtering; load balancing, power factor correction and voltage regulation.

The active power filters, which eliminate the harmonics, can be connected in both shunt and series. Shunt active power filter can perform power factor correction, harmonic filtering when connected at the load terminals. The harmonic filtering approach is based on the principle of injecting harmonic current into the AC system, of the same amplitude and reverse phase to that of the load current harmonics. Dynamic Voltage Restorer (DVR) is a series connected device. The main purpose of this device is to protect sensitive loads from sag/swell interruptions in the supply side. This is accomplished by rapid series voltage injection to compensate for the drop/rise in the supply voltage. Since this is a series device, it can also be used as a series active power filter. Unified Power Quality

Conditioner (UPQC) [5] is a very versatile device that can inject current in shunt and voltage in series simultaneously in a dual control mode.Therefore it can perform both the functions of load compensation and voltage control at the same time.

II. Sources of harmonics

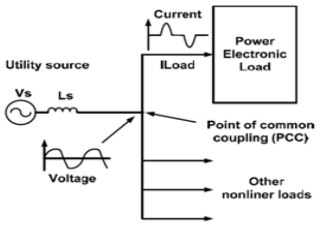

Fig.1.hormonic problems at source side

In Fig.1. The voltage waveform at the Point Common Coupling (PCC) is distorted. Harmonics are considered as one of the most critical problems in electric power systems. Harmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency. For example if the fundamental frequency is 50Hz,then 3rd is 150Hz, 5th is 250Hz Ideally, voltage and current waveforms are perfect sinusoids. However, because of the increased popularity of electronic and non linear loads, these waveforms become distorted. This deviation from a perfect sine wave can be represented by harmonic components having a frequency that is an integral multiple of the fundamental frequency. Thus, a pure voltage or current sine wave has no distortion and no harmonics and a non sinusoidal wave has distortion and harmonics. In order to quantify the distortion, the term of Total Harmonics Distortion (THD) is used. The THD value is the effective value of all the harmonics current added together compared with the value of the fundamental current. The simple block diagram in Fig.1. illustrates the distortion problem due to harmonic at low voltage levels.

3.1. Series active power filter

Series active filter is to be placed in series between the ac source and the load (or harmonic source) to force the source current to become sinusoidal. The approach therefore blocking harmonic current flow from the load to the ac source and from the ac source to the load side.The main advantage of series filters over parallel ones is that they are ideal

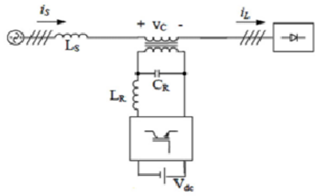

Fig.2.series active filter

Fig.2.Schematic diagram of Series active filter for eliminating voltage-waveform harmonics, and for balancing three-phase voltages.This, in fact, means that this category of filter is used to improve the quality of the system voltage for the benefit of the load. It provides the load with a pure sinusoidal waveform, which is important for voltage-sensitive devices.

3.2. Unified Power Quality Conditioner

The UPQC consists of two three phase inverters connected in cascade in such a manner that inverter II is connected in parallel with the load. Inverter I is connected in series with the supply voltage through a transformer. The main purpose of the shunt compensator is to compensate for the reactive power demanded by the load, to eliminate the harmonics and to regulate the common dc link voltage. Fig.3. Schematic diagram of UPQC The series compensator is operated in PWM voltage controlled mode. It injects voltage in quadrature advance to the supply voltage (current) such that the load end voltage is always maintained at the desired value. The two inverters operate in a coordinated manner.

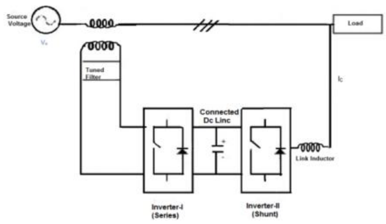

Fig.3.schematic diagram of UPQC

3.3 Control Scheme of Series Active Power Filter

A simple algorithm is developed to control the series and shunt filters. The series filter is controlled such that it injects voltages (V ca ,V cb ,V cc) which cancel out the distortions and/or unbalance present in the supply voltages **(**V sa ,V sb ,V sc **)** thus making the voltages at the PCC (V ls, V lb, V lc) perfectly balanced and sinusoidal with the desired amplitude. In other words, the sum of the supply voltage and the injected series filter voltage makes the desired voltage at the load terminals. The control strategy for the series AF is shown in

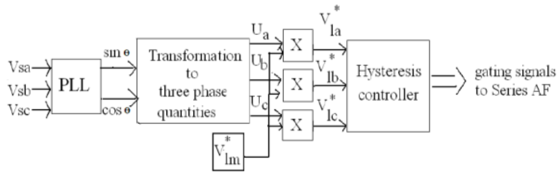

Fig.4.control scheme of series APF

3.4 Reference Voltage Generation & Hysteresis Voltage Controller

Since the supply voltage is unbalanced and or distorted, a phase locked loop (PLL) is used to achieve synchronization with the supply.This PLL converts the distorted input voltage into pure three phase sinusoidal supply of RMS value of each phase equal to that of the fundamental (1 p.u).Three phase distorted/unbalanced supply voltages are sensed and given to the PLL which generates two quadrature unit vectors ($Sin\theta$, $Cos\theta$) **.**The sensed supply voltage is multiplied with a suitable value of gain before being given as an input to the PLL. The in-phase sine and cosine outputs from the PLL are used to compute the supply in phase, 1200 displaced three unit vectors

(u_a ,u_b ,u_c) using eqn.(1) as

$$\begin{bmatrix}u_a\\u_b\\u_c\end{bmatrix}=\begin{bmatrix}1 & 0\\-\frac{1}{2} & -\frac{\sqrt{3}}{2}\\-\frac{1}{2} & \frac{\sqrt{3}}{2}\end{bmatrix}\begin{bmatrix}\sin\theta\\\cos\theta\end{bmatrix}\begin{bmatrix}u_a\\u_b\\u_c\end{bmatrix}=\begin{bmatrix}1 & 0\\-\frac{1}{2} & -\frac{\sqrt{3}}{2}\\-\frac{1}{2} & \frac{\sqrt{3}}{2}\end{bmatrix}\times\begin{bmatrix}Sin\theta\\Cos\theta\end{bmatrix} \quad (1)$$

The computed three in-phase unit vectors are then multiplied with the desired peak value of the PCC phase voltage ($V\ lm^*$), which becomes the three-phase reference PCC voltages as

$$\begin{pmatrix}V_{la}^*\\V_{lb}^*\\V_{lc}^*\end{pmatrix}=V_{lm}^*\begin{pmatrix}u_a\\u_b\\u_c\end{pmatrix} \quad (2)$$

The desired peak value of the PCC phase voltage is considered to be 338V $=\frac{(415*\sqrt{2})}{\sqrt{3}}$

The output of the hysteresis controller is switching signals to the six switches of the VSI of the series AF. The hysteresis controller generates the switching signals such that the voltage at the PCC becomes the desired sinusoidal reference voltage. Therefore, the injected voltage across the series transformer through the ripple filter.

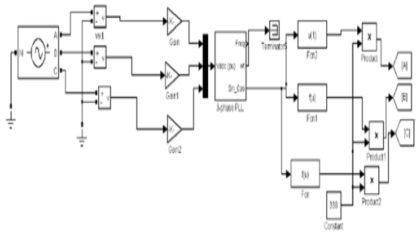

Fig.5. reference voltage generator

cancels out the harmonics and unbalance present in the supply voltage. The MATLAB/Simulink model of the control scheme for series active filter is shown in Fig.5.

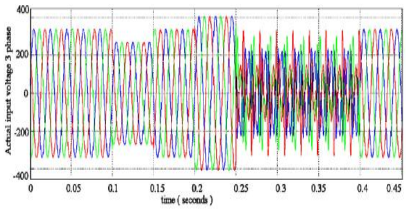

Fig.6. input voltage with distortions

The reference voltages are generated by the Reference voltage generator block is shown in Fig.5.

The system voltage which is fully distorted is shown in Fig.6 After comparing the reference voltages with the load voltage the error signal is passed through Relay block.

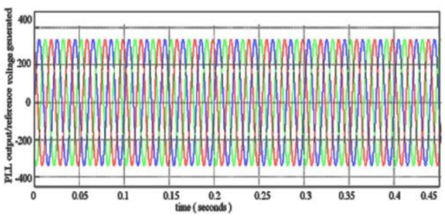

Fig.7. reference voltage generate

Based on comparing the reference voltages with load voltages in a voltage hysteresis controller (Fig.6) gating pulses are generated and given to IGBTs to compensate the disturbances in the system.

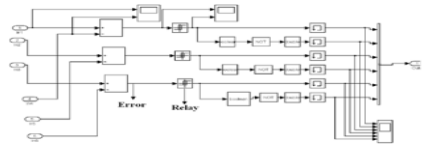

Fig.8.hysteresis voltage controller

The main advantage here to use a hysteresis band controller over a P-I controller is that the former does not require the specifications regarding the system parameters i.e switching frequency , load angle etc. but the latter controller (P-I) requires an additional design criteria for its application analyzed by taking the FFT analysis of the Source and load Voltages**.**

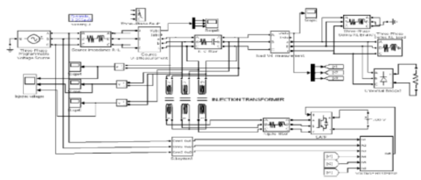

Fig.9. MATLAB/**Simulink** model of proposed series active power filter

III. SIMULATION RESULTS

Case 1

Fig.10 shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 0.4 p.u sag from 0.25 to 0.3 seconds , 0.9 sag from 0.3 to 0.4 seconds and 1p.u voltage from 0.4 to 0.5 seconds.R=50Ω and L=1 mH The SAPF is simulated with only interruptons in the form of Sag, Swell in the input side & the performance of SAPF is

Case – I

Time(seconds)	Voltage (p.u)
0 to 0.1	1
0.1 to 0.15	0.8
0.15 to 0.2	1
0.2 to 0.25	1.2
0.25 to 0.4	(5^{th} & 7^{th} order harmonics) 0.4
0.4 to 0.5	0.9

Table.1. Source Voltage 3-phase (line- Ground)

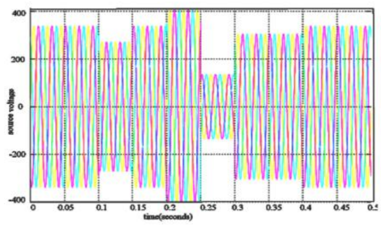

Fig.10.source voltage

Fig.11. shows the compensated voltage injected by each phases to cancel the source side disturbances present in the system.

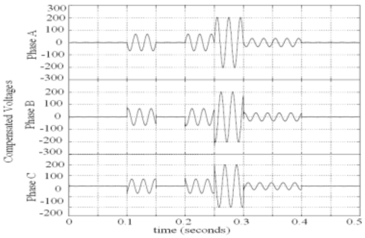

Fig.11. compensated voltages injected for each phases

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in the Fig.12.

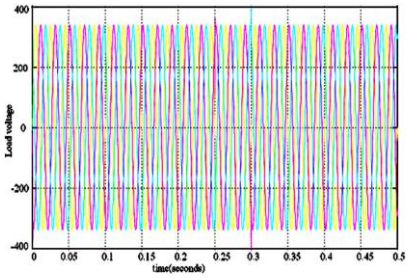

Fig.12. load voltage

The Total harmonic distortion of source voltage is 1.64% and load voltage is 0.04 % as shown in Fig.s 13,1 4. respectively.

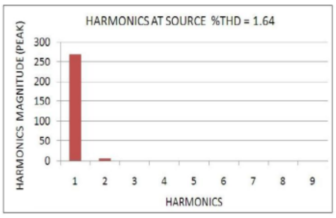

Fig.13. source voltage harmonic spectrum

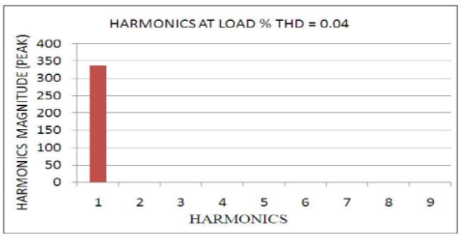

Fig.14.load voltage harmonic spectrum

The SAPF is simulated with only interruptons in the form of Sag, Swell in the input side & the performance of SAPF is analyzed by taking the FFT analysis of the Source and load Voltages**.**

Case .2

Fig.15. shows the source voltage in which rated 1 p.u voltage is created from 0 to 0.1 seconds , 0.8 p.u sag from 0.1 to 0.15 seconds,1 p.u voltage from 0.15 to 0.2 seconds, 1.2 p.u swell from 0.2 to 0.25 seconds , 5th order harmonics of 0.4 p.u and 7th order harmonics of 0.2 p.u from 0.25 to 0.4 seconds, 0.9 sag from 0.4 to 0.5 seconds . the load is R=50Ω and L=10 mH.

Case-II

Time(seconds)	Voltage (p.u)
0 to 0.1	1
0.1 to 0.15	0.8
0.15 to 0.2	1
0.2 to 0.25	1.2
0.25 to 0.3	0.4
0.3 to 0.4	0.9
0.4 to 0.5	1

Table.2. Source Voltage 3-phase (line-Ground)

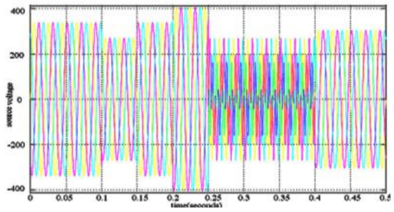

Fig.15. source voltage

Fig.16. shows the compensated voltage injected by each phases to cancel the source side disturbances present in the system.

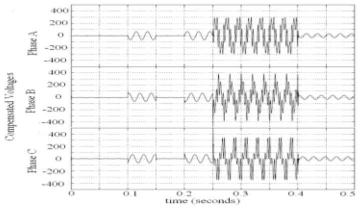

Fig.16. Compensated voltages injected for each phases

Due to the injection of the above voltages through the injection transformer in series with the line the load voltage is sinusoidal as shown in the Fig. 17.

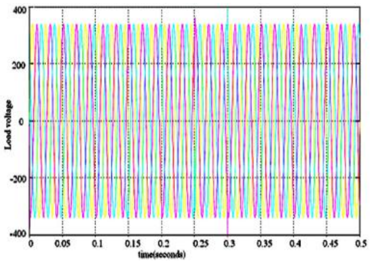

Fig.17. load voltage

The Total harmonic distortion of source voltage is 64.37% and load voltage is 0.72 % as shown in Fig.18, Fig.19. espectively.

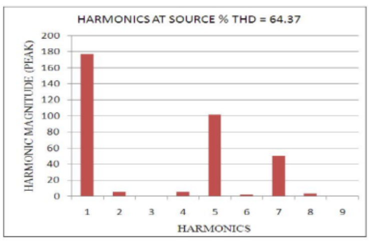

Fig.18.source voltage harmonic spectrum

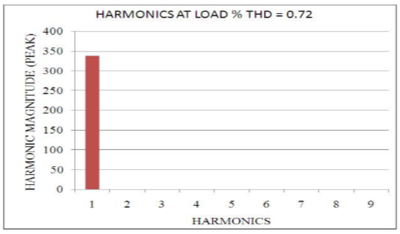

Fig.19.load voltage harmonic spectrum

The SAPF is simulated with interruptions in the form of Sag, Swell & harmonics in the input side(5th & 7th) & the performance of SAPF is analyzed by taking the FFT analysis of the Source and load Voltages.

IV. Conclusion

A Series active power filter has been investigated for power quality improvement. Various simulations are carried out to analyze the performance of the system. Hysteresis controller based Series active power filter is implemented for harmonic and voltage distortion compensation of the non-linear load. The Simulation is even extended for abnormal faults occurring on the power system like L-G & L-L faults. The simulation results of series active power filter has shown the ability to compensate voltage sag, swell and harmonics present at input source side. With these functions, the proposed SAPF is suitable for connecting at the PCC of industrial drives which are most sensitive to Sags, Swells and harmonics. The THD of the load voltage is below 5%, the harmonics limit imposed by IEEE standard.

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BIOGRAPHICS

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