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POWER QUALITY IMPROVEMENT BY UPQC

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ABSTRACT : Any electrical power system consists of wide range of electrical, electronic and power electronic equipments in commercial and industrial applications. The quality of the power is affected by many factors like harmonic contamination, due to the increment of non-linear loads, sag and swell due to the switching of the loads. Since most of the electronic equipment is nonlinear in nature these will induce harmonics in the system, which affect the sensitive loads to be fed from the system. These problems are partially solved with the help of LC passive filters. However, this kind of filter cannot solve random variation in the load current wave form and voltage wave form. Active filters can resolve this problem. However, the cost of active filters is high, difficult to implement in large scale. One of the many solutions is the use of a combined system of shunt and active series filters like unified power quality conditioner which aims at achieving a low cost under highly effective control. The Unified Power Quality Conditioner (UPQC) device combines a shunt active filter together with a series active filter in a back-to-back configuration, to simultaneously compensate the supply voltage and the load current or to mitigate any type of voltage and current fluctuations and power factor correction in a power distribution network, such that improved power quality can be made available at the point of common coupling. The present work study the compensation principle and different control strategies used here are based on PI controller of the UPQC in detail. The control strategies are modeled using MATLAB/SIMULINK. The performance is also observed under influence of utility side disturbances such as harmonics, flicker and spikes. The simulation results are listed in comparison of different control strategies and for the verification of results.

***Keywords*: -** UPQC, Power quality, Series and Shunt Active filters, Sag and Swell harmonics.

I. INTRODUCTION

With the advent of power semiconductor switching devices, like thyristors, GTO's (Gate Turn off thyristors), IGBT's (Insulated Gate Bipolar Transistors) and many more devices, control of electric power has become a reality. Such power electronic controllers are widely used to feed electric power to electrical loads, such as adjustable speed drives (ASD's), furnaces, computer power supplies, HVDC systems etc. The power electronic devices due to their inherent non-linearity draw harmonic and reactive power from the supply. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor.

In addition to this, the power system is subjected to various transients like voltage sags, swells, flickers etc. These transients would affect the voltage at distribution levels. Excessive reactive power of loads would increase the generating capacity of generating stations and increase the transmission losses in lines. Hence supply of reactive power at the load ends becomes essential. Power Quality (PQ) mainly deals with issues like maintaining a fixed voltage at the Point of Common Coupling (PCC) for various distribution voltage levels irrespective of voltage fluctuations, maintaining near unity power factor power drawn from the supply, blocking of voltage and current unbalance from passing upwards from various distribution levels, reduction of voltage and current harmonics in the system and suppression of excessive supply neutral current.

Conventionally, passive LC filters and fixed compensating devices with some degree of variation like thyristor switched capacitors, thyristor switched reactors were employed to improve the power factor of ac loads. Such devices have the demerits of fixed compensation, large size, ageing and resonance. Nowadays equipments using power semiconductor devices, generally known as active power filters (APF's), Active Power Line Conditioners (APLC's) etc. are used for the power quality issues due to their dynamic and adjustable solutions. Flexible AC Transmission Systems (FACTS) and Custom Power products like STATCOM (Static synchronous Compensator), DVR (Dynamic Voltage Restorer), etc. deal with the issues related to power quality using similar control strategies and concepts. Basically, they are different only in the location in a power system where they are deployed and the objectives for which they are deployed.

Active Power Filters can be classified, based on converter type, topology and the number of phases. Converter types are Current Source Inverter (CSI) with inductive energy storage or Voltage Source Inverter (VSI) with capacitive energy storage. The topology can be shunt, series or combination of both. Unified Power Quality Conditioner (UPQC), which can be used at the PCC for improving power quality, is designed; simulated using proposed control strategy and the performance is evaluated for various nonlinear loads.

II. Classifications of Active Power Filters

A. Converter based classification

Current Source Inverter (CSI) Active Power Filter (Fig 2.1) and Voltage Source Inverter Active Power Filter (VSI) (Fig 2.2) are two classifications in this category. Current Source Inverter behaves as a non-sinusoidal current source to meet the harmonic current requirement of the nonlinear loads. A diode is used in series with the self-commutating device (IGBT) for reverse voltage blocking. However, GTO-based configurations do not need the series diode, but they have restricted frequency of switching. They are considered sufficiently reliable, but have higher losses and require higher values of parallel ac power capacitors. Moreover, they cannot be used in multilevel or multistep modes to improve performance in higher ratings.

The other converter used as an AF is a voltage-fed PWM inverter structure, as shown in Fig 2.2. It has a self-supporting dc voltage bus with a large dc capacitor. It has become more dominant, since it is lighter, cheaper, and expandable to multilevel and multistep versions, to enhance the performance with lower switching frequencies. It is more popular in UPS-based applications, because in the presence of mains, the same Inverter Bridge can be used as an AF to eliminate harmonics of critical nonlinear loads.

B. Topology based Classification

AF's can be classified based on the topology used as series or shunt filters, and unified power quality conditioners use a combination of both. Combinations of active series and passive shunt filtering are known as hybrid filters. Fig 2.3 is an example of an active shunt filter, which is most widely used to eliminate current harmonics, reactive power compensation (also known as STATCON), and balancing unbalanced currents. It is mainly used at the load end, because current harmonics are injected by nonlinear loads. It injects equal compensating currents, opposite in phase, to cancel harmonics and/or reactive components of the nonlinear load current at the point of connection. It can also be used as a static VAR generator (STATCON) in the power system network for stabilizing and improving the voltage profile.

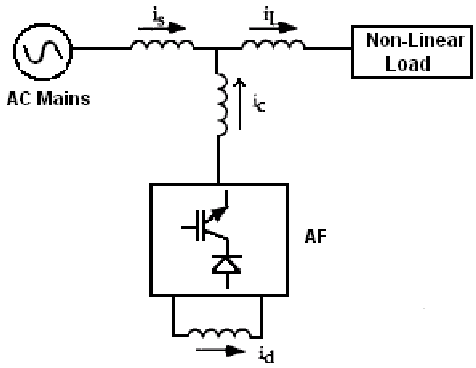

Fig 2 1 Current fed by AF

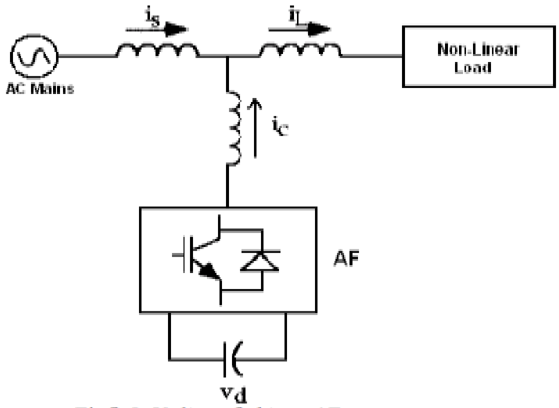

Fig 2 .2 Voltage fed type AF

Fig 2.4 shows the basic block of a stand-alone active series filter. It is connected before the load in series with the mains, using a matching transformer, to eliminate voltage harmonics, and to balance and regulate the terminal voltage of the load or line. It has been used to reduce negative-sequence voltage and regulate the voltage on three-phase systems. It can be installed by electric utilities to compensate voltage harmonics and to damp out harmonic propagation caused by resonance with line impedances and passive shunt compensators.

Fig 2.5 shows the hybrid filter, which is a combination of an active series filter and passive shunt filter. It is quite popular because the solid-state devices used in the active series part can be of reduced size and cost (about 5% of the load size) and a major part of the hybrid filter is made of the passive shunt L–C filter used to eliminate lower order harmonics. It has the capability of reducing voltage and current harmonics at a reasonable cost.

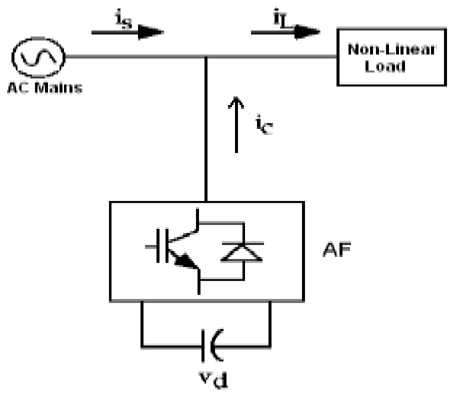

Fig 2.3 Shunt-type AF

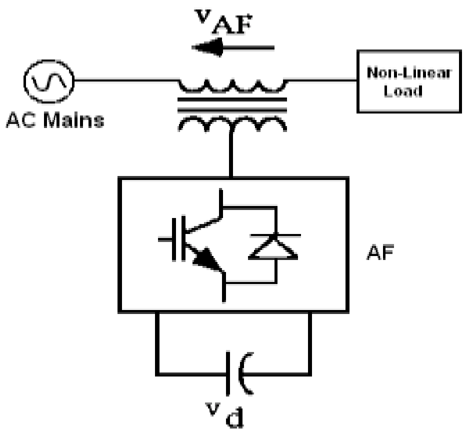

Fig 2 .4 Series-type AF

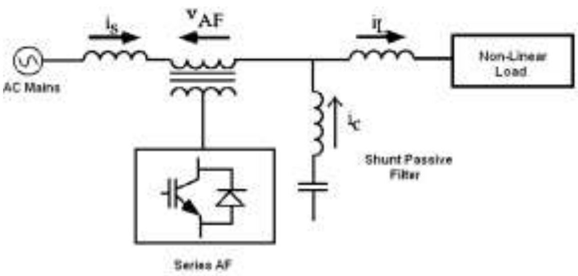

Fig 2.5 Hybrid filter

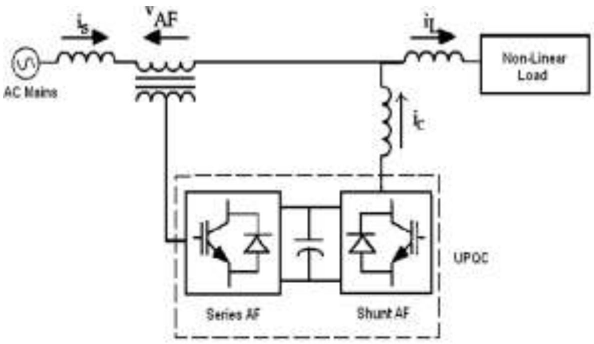

Fig 2.6 Unified Power Quality Conditioner

Fig 2.6 shows a unified power quality conditioner (also known as a universal AF), which is a combination of active shunt and active series filters. The dc-link storage element (either inductor or dc-bus capacitor) is shared between two current-source or voltage-source bridges operating as active series and active shunt compensators. It is used in single-phase as well as three-phase configurations. It is considered an ideal AF, which eliminates voltage and current harmonics and is capable of giving clean power to critical and harmonic-prone loads, such as computers, medical equipment, etc. It can balance and regulate terminal voltage and eliminate negative-sequence currents. Its main drawbacks are its large cost and control complexity because of the large number of solid-state devices involved.

III. VARIOUS CONTROL STRATEGIES FOR APF'S

A. Error Saw tooth Control

Error saw tooth control produces a PWM signal by first differencing the power system waveform with the desired signal. The error signal is then compared with a saw tooth wave and the points of intersection gives the switching instants. The overall scheme for error saw tooth control is given in Fig 4.1.When considering the error saw tooth control as continuous linear system, smaller steady state error requires larger gain; the sampled nature of the switching converter will result in instability for larger loop gain. For medium loop gain the tracking error will converge to a limited steady state error with constant switch frequency contribution.

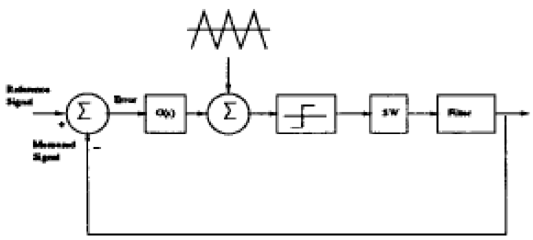

Fig 3.1 Block diagram of error saw tooth control.

B. Hysteresis control

Hysteresis band PWM is basically an instantaneous feedback current control method of PWM where the actual current continuously tracks the command current within a hysteresis band. The control circuit generates the sine reference current wave of desired magnitude and frequency. It is compared with the actual phase current wave. When the current exceeds a prescribed hysteresis band, appropriate switches are turned on so that actual current is within the hysteresis band. Hysteretic control operation is illustrated in Fig 3.2.

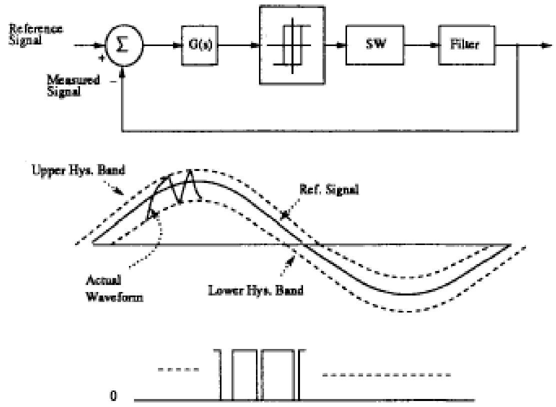

Fig. 3.2 Hysteresis control operation.

This method is simple to implement in analog hardware up to quite high switch rates. The disadvantage of hysteresis control is that both the hysteresis level and the system determine the switch rate. When the switch device is required to operate near its switch rate limit, the variation of the rate with system changes is unacceptable. This control law is still proportional to error and will give poor damping performance in the control of resonant systems.

IV. PROPOSED UNIFIED POWER QUALITY CONDOTIONER

Basic block diagram of UPQC is shown in Fig 4.1, where as the overall control circuit is shown in the Fig 4.3. The voltage at PCC may be or may not be distorted depending on the other non-linear loads connected at PCC. Here we assume the voltage at PCC is distorted. Two voltage source inverters are connected back to back, sharing a common dc link. One inverter is connected parallel with the load. It acts as shunt APF, helps in compensating load harmonic current as well as to maintain dc link voltage at constant level. The second inverter is connected in series with utility voltage by using series transformers and helps in maintaining the load voltage sinusoidal.

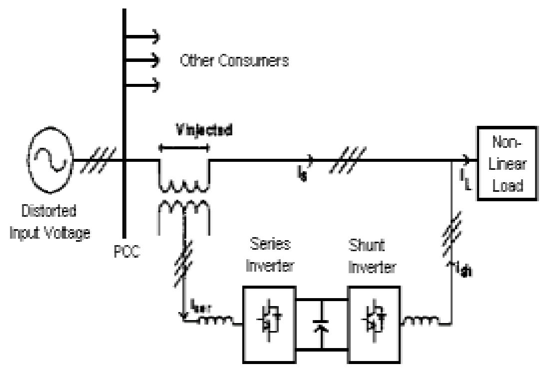

Fig 4.1 Basic Block Diagram of UPQC

A. Reference generation (Phase Locked Loop)

Reference currents and voltages are generated using Phase Locked Loop (PLL). The control strategy is based on the extraction of Unit Vector Templates from the distorted input supply. These templates will be then equivalent to pure sinusoidal signal with unity (p.u.) amplitude. The extraction of unit vector templates is shown in the Fig 4.2.

The 3-ph distorted input source voltage at PCC contains fundamental component and distorted component. To get unit input voltage vectors U_{abc}, the input voltage is sensed and multiplied by gain equal to $1/V_m$, where V_m is equal to peak amplitude of fundamental input voltage. These unit input voltage vectors are taken to phase locked loop (PLL). With proper phase delay, the unit vector templates are generated.

$$\begin{aligned} Ua &= \mathrm{Sin}\,(wt) \\ Ub &= \mathrm{Sin}\,(wt-120) \qquad (1) \\ Uc &= \mathrm{Sin}\,(wt+120) \end{aligned}$$

Multiplying the peak amplitude of fundamental input voltage with unit vector templates of equation (1) gives the reference load voltage signals,

$$V^*abc = Vm.\ Uabc \qquad (2)$$

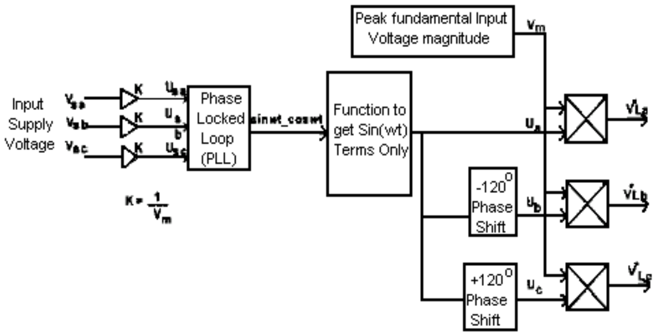

Fig 4.2 Extraction of Unit Vector Templates and 3-Ph Reference Voltages

In order to have distortion less load voltage, the load voltage must be equal to these reference signals. The measured load voltages are compared with reference load voltage signals. The error generated is then taken to a hysteresis controller to generate the required gate signals for series APF. The unit vector template can be applied for shunt APF to compensate the harmonic current generated by non-linear load. The shunt APF is used to compensate for current harmonics as well as to maintain the dc link voltage at constant level. To achieve the abovementioned task the dc link voltage is sensed and compared with the reference dc link voltage. A PI controller then processes the error. The output signal from PI controller is multiplied with unit vector templates of equation (1) giving reference source current signals. The source current must be equal to this reference signal. In order to follow this reference current signal, the 3-ph source currents are sensed and compared with reference current signals. The error generated is then processed by a hysteresis current controller with suitable band, generating gating signals for shunt APF.

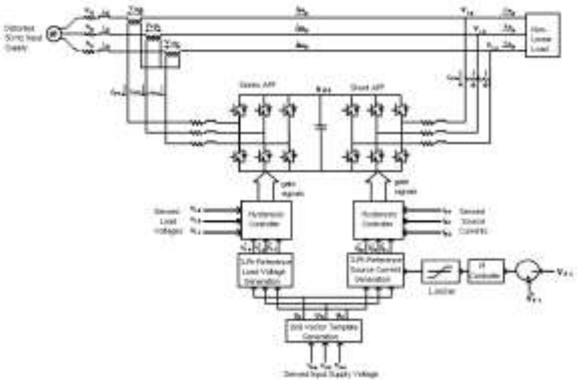

Fig 4.3 Overall Control Circuit Configuration of UPQC

B. MODULATION METHOD (Hysteresis control)

The UPQC uses two back-to-back connected three phase VSI's sharing a common dc bus. The hysteresis controller is used here to control the switching of the both VSI's.

Hysteresis control law for Series APF:

If (V_{act}) > (V_{ref} + HB) upper switch of a leg is ON and lower switch is OFF.

If (V_{act}) < (V_{ref} - HB) upper switch of a leg is OFF and lower switch is ON.

Hysteresis control law for Shunt APF:

If (i_{act}) > (i_{ref} + HB) upper switch of a leg is ON and lower switch is OFF.

If (i_{act}) < (i_{ref} - HB) upper switch of a leg is OFF and lower switch is ON.

Where HB is the hysteresis band.

C. MATLAB/SIMULINK MODEL

The SimPower Systems (SPS) Matlab/Simulink based simulation model of proposed UPQC is shown in Fig 5.4. The load is realized by using a diode bridge rectifier followed by a RL load. The distortion in the supply voltage is introduced by connecting a 5^{th} (20% of the fundamental input) and 7^{th} (10% of fundamental input) harmonic voltage sources in series with the utility voltage. Both the series and shunt APF's are realized by six IGBT switches each, sharing a common dc link.

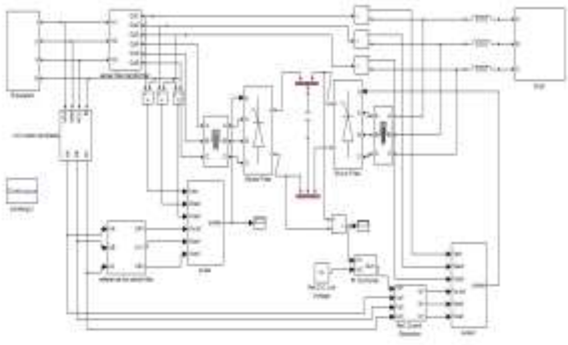

Figure 4.4 UPQC simulation model

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D. SIMULATION RESULTS

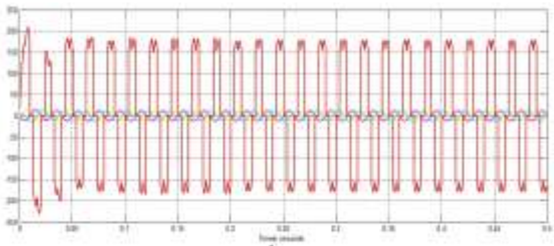

Fig 4.5 Load Voltage

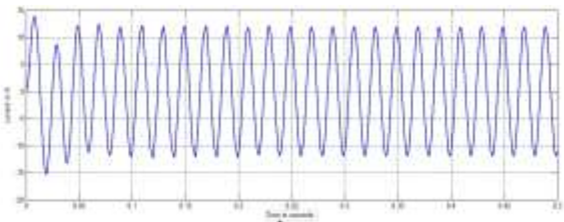

Fig 4.6 Load current

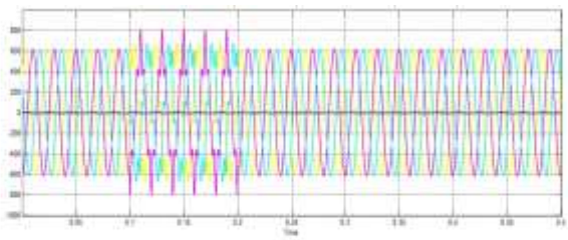

Fig 4.7 system voltage

The source current waveform is shown in Fig 4.6 Before time '0.2 sec', the source current is equal to load current. But after time '0.2 sec', when shunt APF starts maintaining dc link voltage; it injects the compensating current in such a way that the source current becomes sinusoidal. Source Voltage and Current are shown in Fig 4.7.

V. CONCLUSIONS

Custom power devices like DVR, D-STATCOM, and UPQC can enhance power quality in the distribution system. Based on the power quality problem at the load or at the distribution system, there is a choice to choose particular custom power device with specific compensation. Unified Power Quality Conditioner (UPQC) is the combination of series and shunt APF, which compensates supply voltage and load current imperfections in the distribution system. The UPQC considered in this project is a multifunction power conditioner which can be used to compensate for various voltage disturbance of the power supply, to correct any voltage fluctuation and to prevent the harmonic load current from entering the power system.

A simple control technique based on unit vector templates generation is proposed for UPQC. Proposed model has been simulated in MATLAB. The simulation results show that the input voltage harmonics and current harmonics caused by non-linear load can be compensated effectively by the proposed control strategy. The closed loop control schemes of direct current control, for the proposed UPQC have been described. A suitable mathematical model of the UPQC has been developed with different shunt controllers and simulated results have been described. The performance is also observed under influence of utility side disturbances such as harmonics, flicker and spikes.

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