Abstract — Active Power Filters mainly divided based on converters used, i.e. 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. The third classification is based on the number of phases, such as single phase systems, three phase systems or three phase four wire systems. Criterion for selection of dc link capacitor and interfacing filter design are also discussed.

Index Terms — UPQC, VSI, FACTS, Stastcom

I. INTRODUCTION

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) has become an important issue since many loads at various distribution ends like adjustable speed drives, process industries, printers, domestic utilities, computers, microprocessor based equipment’s etc. have become intolerant to voltage fluctuations, harmonic content and interruptions. [1]Power Quality (PQ) is mainly concentrating with issues like fixing a constant 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, a passive LC filters and fixed compensating devices with some degree of variation like TCS, TSC were employed to improve the power factor of ac loads. Such devices have the demerits of fixed compensation, large size, ageing and resonance. Nowadays equipment’s using power semiconductor devices, generally known as active power filters (APFs), 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 problems related to power quality using similar control strategies and concepts. Dynamic Modeling Of H-bridge the different only in the location in a power system where they are deployed and the objectives for which they are deployed.

II. LITERATURE SURVEY

Power electronic based power processing offers higher efficiency, compact size and better controllability. But on the flip side, due to switching actions, these systems behave as non-linear loads [1-3]. Therefore, whenever, these systems are connected to the utility, they draw non-sinusoidal and/or lagging current from the source. As a result these systems pose themselves as loads having poor displacement as well as distortion factors. Hence they draw considerable reactive volt-amperes from the utility and inject harmonics in the power networks. Until now, to filter these harmonics and to compensate reactive power at factory level, only capacitor and passive filters were used. Passive filters have been widely used for the harmonic and reactive power mitigation in the power lines earlier. They are suitable for only eliminating only few harmonics, large size, ageing and resonance. More recently, new PWM based converters for motor control are able to provide almost unity power factor operations. [2]This situation leads to two observations: on one hand, there is electronic equipment which generates harmonics and, on the other hand, there is unity power factor...
motor drive system which doesn't need power factor correction capacitor. Also, we cannot depend on this capacitor to filter out those harmonics. This is one of the reasons that the research is being done in the area of APF and less pollutant drives. Loads, such as, diode bridge rectifier or a thyristor bridge feeding a highly inductive load, presenting themselves as current source at point of common coupling (PCC), can be effectively compensated by connecting an APF in shunt with the load [4-6]. On the other hand, there are loads, such as Diode Bridge having a high dc link capacitive filter. These types of loads are gaining more and more importance mainly in forms of AC to DC power supplies and front end AC to DC converters for AC motor drives. The voltage injected in series with the load by series converter is made to follow a control law such that the sum of this injected voltage and the input voltage is sinusoidal. Thus, if utility voltages are non-sinusoidal or unbalanced, due to the presence of other clients on the same grid, proper selection of magnitude and phase for the injected voltages will make the voltages at load end to be balanced and sinusoidal.[4] The shunt APF acts as a current source and inject a compensating harmonic current in order to have sinusoidal, in-phase input current and the series APF acts as a voltage source and inject a compensating voltage in order to have sinusoidal load voltage. The developments in the digital electronics, communications and in process control system have increased the number of sensitive loads that require ideal sinusoidal supply voltage for their proper operation. In order to meet limits proposed by standards it is necessary to include some sort of compensation. In the last few years, solutions based on combination of series active and shunt active filter have appeared. Its main purpose is to compensate for supply voltage and load current imperfections, such as, sags, swells, interruptions, imbalance, flicker, voltage imbalance, harmonics, reactive currents, and current unbalance[10-15]. This combination of series and shunt APF is called as Unified Power Quality Conditioner (UPQC). In most of the articles control techniques suggested are complex requiring different kinds of transformations. The control technique presented here is very simple and does not require any transformation.

III. GENERALIZED THEORY OF ACTIVE POWER FILTERS

It has become imperative to maintain the sinusoidal nature of voltage and currents in the power system. Various international agencies like IEEE and IEC have issued standards, which put limits on various current and voltage harmonics. The limits for various current and voltage harmonics specified by IEEE-519 for various frequencies are given in Table 1.

The objectives and functions of active power filters have expanded from reactive power compensation, voltage regulation, etc. to harmonic isolation between utilities and consumers, and harmonic damping throughout the distribution as harmonics propagate through the system. Active power filters are either installed at the individual consumer premises or at substation and/or on distribution feeders. Depending on the compensation objectives, various types of active power filter topologies have evolved.

3.1. Converter based classification

Current Source Inverter (CSI) Active Power Filter (Fig.1) and Voltage Source Inverter Active Power Filter (VSI) (Fig 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.[3] 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. 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.

3.2. 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 3. is an example of an active shunt filter, which is most widely used to eliminate current harmonics, reactive power compensation (also known as STATCOM), 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
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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 1 Current fed type AF

Fig 2 Voltage fed type AF

Fig 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.[5] 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 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 3. Shunt-type AF

Fig 4 Series-type AF

Fig 5 Hybrid filter

Fig 6 Unified Power Quality Conditioner
Fig 6 shows a unified power quality conditioner, which is a combination of active shunt and active series filters. The dc-link storage element 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.

IV. THREE PHASE FOUR WIRE (3P4W) UPQC STRUCTURE

Generally, a 3P4W distribution system is realized by providing a neutral conductor along with three power conductors from generation station or by utilizing a three-phase Δ-Y transformer at distribution level. Fig. 7 shows a 3P4W network in which the neutral conductor is provided from the generating station itself, where Fig. 4.6 shows a 3P4W distribution network considering a Δ-Y transformer. Assume a plant site where three-phase three-wire UPQC is already installed to protect a sensitive load and to restrict any entry of distortion from load side toward utility, as shown in Fig. 8. If we want to upgrade the system now from 3P3W to 3P4W due to installation of some single-phase loads and if the distribution transformer is close to the plant under consideration, utility would provide the neutral conductor from this transformer without major cost involvement. In certain cases, this may be a costly solution because the distribution transformer may not be situated in close vicinity.

Recently, the utility service providers are putting more and more restrictions on current total harmonic distortion (THD) limits, drawn by nonlinear loads, to control the power distribution systems harmonic pollution. At the same time, the use of sophisticated equipment/load has increased significantly, and it needs clean power for its operation. Therefore, in future distribution systems and plant/load centers, application of UPQC would be common.

The 3P4W topology that can be realized from 3P3W system is shown in the Fig.9. This system has all the advantages of general UPQC, in addition to easy expansion of 3P3W system to 3P4W system. [6]Thus, this topology may play an important role in the future 3P4W distribution system for more advanced UPQC-based plant/load center installation, where utilities would be having an additional option to realize a 3P4W system just by providing a 3P3W supply.

As shown in Fig. 8, the UPQC should necessarily consist of three-phase series transformer in order to connect
one of the inverters in the series with the line to function as a controlled voltage source. If we could use the neutral of three-phase series transformer to connect a neutral wire to realize the 3P4W system, then 3P4W system can easily be achieved from a 3P3W system (Fig. 7). The neutral current, present if any, would flow through this fourth wire toward transformer neutral point. [7] This neutral current can be compensated by using a split capacitor topology or a four-leg voltage-source inverter (VSI) topology for a shunt inverter. The four-leg VSI topology requires one additional leg as compared to the split capacitor because the split capacitor topology essentially needs two capacitors and an extra control loop to maintain a zero voltage error difference between both the capacitor voltages, resulting in a more complex control loop to maintain the dc bus voltage at constant level. The four-leg VSI topology is considered to compensate the neutral current flowing toward the transformer neutral point. A fourth leg is added on the existing 3P3W UPQC, such that the transformer neutral point will be at neutral point will be at virtual zero potential.

Fig. 10. UPQC structure

V. MATLAB/SIMULINK RESULTS
Unified power quality conditioning system (UPQC) consists of three VSCs in which two VSCs are connected in series to the two feeders and one VSC is connected in parallel to load end of the first feeder. [8] These three VSCs connected back to back through a common dc-link capacitor. Each of the VSCs in Fig. 11 is realized by a three-phase converter with a commutation reactor and high-pass output filter. The commutation reactor and high-pass output filter are connected to prevent the flow of switching harmonics into the power supply.

Fig. 11. Simulink block diagram of UPQC

The purpose of UPQC is to regulate the load voltages against voltage sags, voltage swells and disturbances in the system and to compensate the reactive and harmonic components of nonlinear load currents

5.1 Implementation of VSCs
The structure of VSC is shown in the Fig. 12

Fig. 12. Simulink block diagram of VSCs

In the internal structure of UPQC three VSCs are present. Out of three VSCs, two VSCs are operating as voltage controllers and one VSC is operating as current controller. Each VSC consists of six switches (IGBTs) are present.

5.2 Implementation of Series Transformer
The UPQC should necessarily consist of two three-phase series transformer in order to connect the two VSCs in series with the lines to function as a controlled voltage sources.

5.3. Implementation of Shunt and Series Controllers

The switching control strategy used for shunt VSC is hysteresis current control. The purpose of this shunt controller is to compensate reactive and harmonic component of load L1 current. In this block the load current is detected and then transformed into the synchronous dq0 frame. A low pass filter is used to extract the harmonics. The PI controller is used to regulate the dc-link capacitor voltage. The Simulink block diagram of series controller is shown in the Fig. 14.

The simulation results with the modified topology are shown in Figs. In this topology, the value of the capacitor (Cf) in the shunt active filter branch is chosen to be 65 μF, and total dc bus voltage is maintained at 560 V. The voltage across the series capacitor in phase-a (vcfa) and the phase-a load voltage (vla) are shown in Fig. From this figure, it is clear that the voltage across the capacitor is in phase opposition to the terminal voltage. According to (16), the voltage across the capacitor adds to the dc-link voltage and injects the required compensation currents into the PCC.

Fig. 13. Simulink diagram of three-phase series transformer

Fig. 14. Simulink block diagram of shunt controller

Fig. 15. Simulink block diagram of series controller

5.4. SIMULATION RESULTS:

The simulation results using conventional topology. Terminal voltages with sag, DVR-injected voltages, and load voltages after compensation.
VI. CONCLUSION

A modified UPQC topology for three-phase four-wire system has been proposed in this paper, which has the capability to compensate the load at a lower dc-link voltage under non stiff source. Design of the filter parameters for the series and shunt active filters is explained in detail. The proposed method is validated through simulation and experimental studies in a three-phase distribution system with neutral-clamped UPQC topology (conventional). The proposed modified topology gives the advantages of both the conventional neutral-clamped topology and the four-leg topology. Detailed comparative studies are made for the conventional and modified topologies. From the study, it is found that the modified topology has less average switching frequency, less THDs in the source currents, and load voltages with reduced dc-link voltage as compared to the conventional UPQC topology.

REFERENCES