IJMTST | Volume: 2 | Issue: 03 | March 2016 | ISSN: 2455-3778

A New Topology for Power Quality Improvement using 3-Phase 4-Wire UPQC with Reduced DC-Link Voltage Rating

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ABSTRACT

This paper introduces a new concept of optimal utilization of a Unified power quality conditioner (UPQC). The series inverter of UPQC is controlled to perform simultaneous Methods: voltage sag/swell compensation and load reactive power sharing with the shunt inverter. The active power control approach is used to compensate voltage sag/swell and is integrated with theory of power angle control (PAC) of UPQC to coordinate the load reactive power between the two inverters. MATLAB/SIMULINK-based simulation results are discussed to support the developed concept. Finally, the proposed UPQC concept is validated.

KEYWORDS: *Power angle control, UPQC, MATLAB/SIMULINK*

I. INTRODUCTION

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. The third classification is based on the number of phases, such as single phase systems, three phase systems or three phase four wire systems.

In this paper, various extraction algorithms for generating reference signals and various modulation techniques for generating pulses already developed and published are discussed. Criterion for selection of dc link capacitor and interfacing filter design are also discussed. The Objective of this thesis, one such APLC known as 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 (steel plant loads).

II. LITERATURE SURVEY

More recently, new PWM based converters for motor control are able to provide almost unity power factor operations. 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 . 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. For these types of loads APF has to be connected in series with the load. The voltage injected in series with the load by series APF 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.

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. 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. 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 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 (STATCOM) in the power system network for stabilizing and improving the voltage profile.

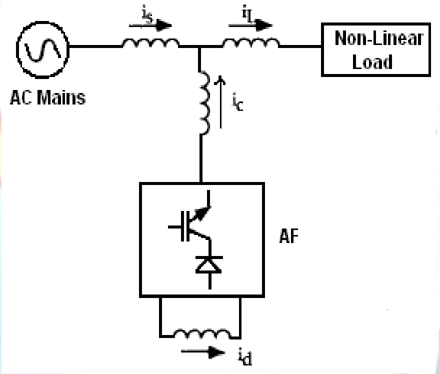

Fig.1 Current fed type AF

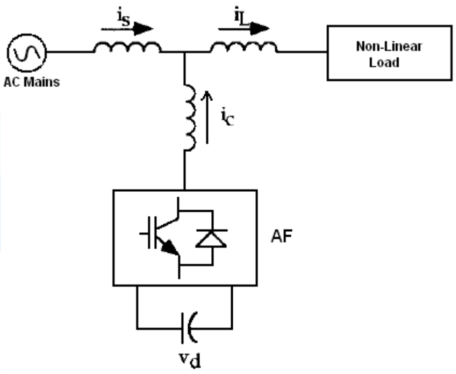

Fig.2 Voltage fed type AF

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. 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.

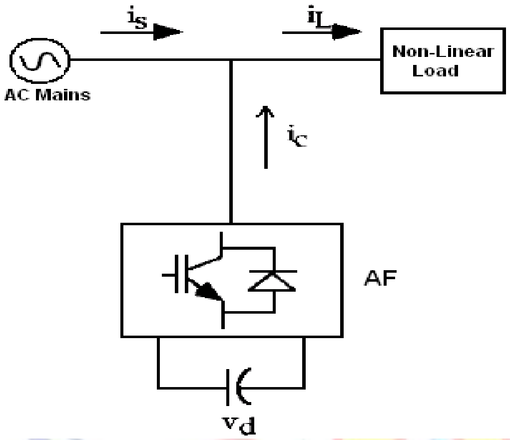

Fig .3 Shunt-type AF

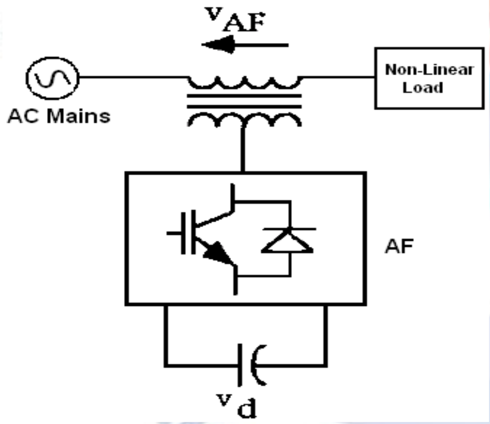

Fig .4 Series-type AF

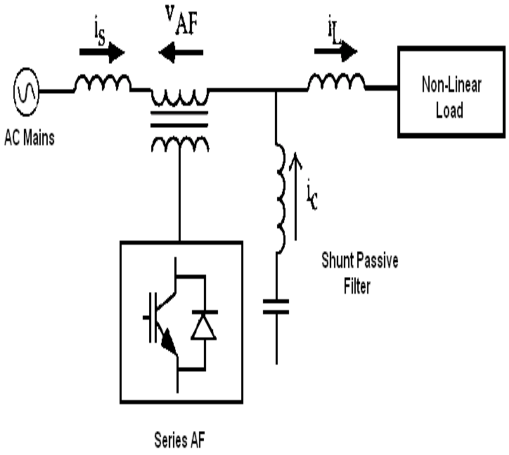

Fig .5 Hybrid filter

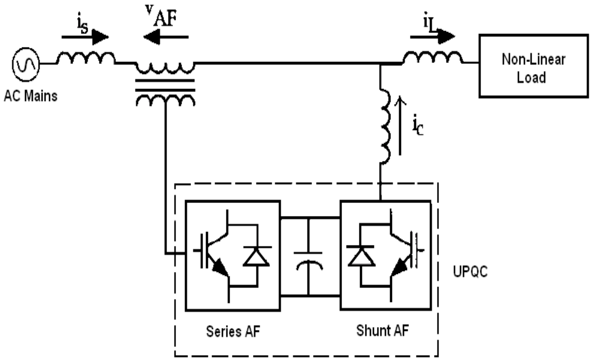

Fig .6 Unified Power Quality Conditioner

Fig .6 shows a unified power quality conditioner (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.

A. *Supply-System-Based Classification*

This classification of AF's is based on the supply and/or the load system having single-phase (two wire) and three-phase (three wire or four wire) systems. There are many nonlinear loads, such as domestic appliances, connected to single-phase supply systems. Some three-phase nonlinear loads are without neutral, such as ASD's, fed from three-wire supply systems. There are many nonlinear single-phase loads distributed on four-wire three-phase supply systems, such as computers, commercial lighting, etc. Hence, AF's may also be classified accordingly as two-wire, three-wire, and four-wire types.

1. Two-Wire AF's:

Two-wire (single phase) AF's are used in all three modes as active series, active shunt, and a combination of both as unified line conditioners. Both converter configurations, current-source PWM bridge with inductive energy storage element and voltage-source PWM bridge with capacitive dc-bus energy storage elements, are used to form two-wire AF circuits. In some cases, active filtering is included in the power conversion stage to improve input characteristics at the supply end.

2. Three-Wire AF's:

Three-phase three-wire nonlinear loads, such as ASD's, are major applications of solid-state power converters and, lately, many ASD's, etc., incorporate AF's in their front-end design. A large number of publications have appeared on three-wire AF's with different configurations. All the configurations shown in Figs1–Fig6. are developed, in three-wire AF's, with three wires on the ac side and two wires on the dc side. Active shunt AF's are developed in the current-fed type (Fig .1) or voltage-fed type with single-stage (Fig.2) or multi-step/multilevel and multi-series configurations. Active shunt AF's are also designed with three single-phase AF's with isolation transformers for proper voltage matching, independent phase control, and reliable compensation with unbalanced systems. Active series filters are developed for stand-alone mode (Fig.4) or hybrid mode with passive shunt filters (Fig.5). The latter (hybrid) has become quite popular to reduce the size of power devices and cost of the overall system. A combination of active series and active shunt is used for unified power quality conditioners (Fig .6) and universal filters.

3. Four-Wire AF's:

A large number of single-phase loads may be supplied from three-phase mains with neutral conductor. They cause excessive neutral current, harmonic and reactive power burden, and unbalance. To reduce these problems, four-wire AF's have been attempted. They have been developed as: 1) active shunt mode with current feed and voltage feed; 2) active series mode; and 3) hybrid form with active series and passive shunt mode.

B. Operation of Three Phase Active Power Filters

The basic configuration of a three-phase three-wire active power filter is shown in Fig .7. The diode bridge rectifier is used as an ideal harmonic generator to study the performance of the Active filter. The current-controlled voltage-source inverter (VSI) is shown connected at the load end. This PWM inverter consists of six switches with anti parallels diode across each switch. The capacitor is designed in order to provide DC voltage with acceptable ripples. In order to assure the filter current at any instant, the DC voltage V_{dc} must be at least equal to 3/2 of the peak value of the line AC mains voltage.

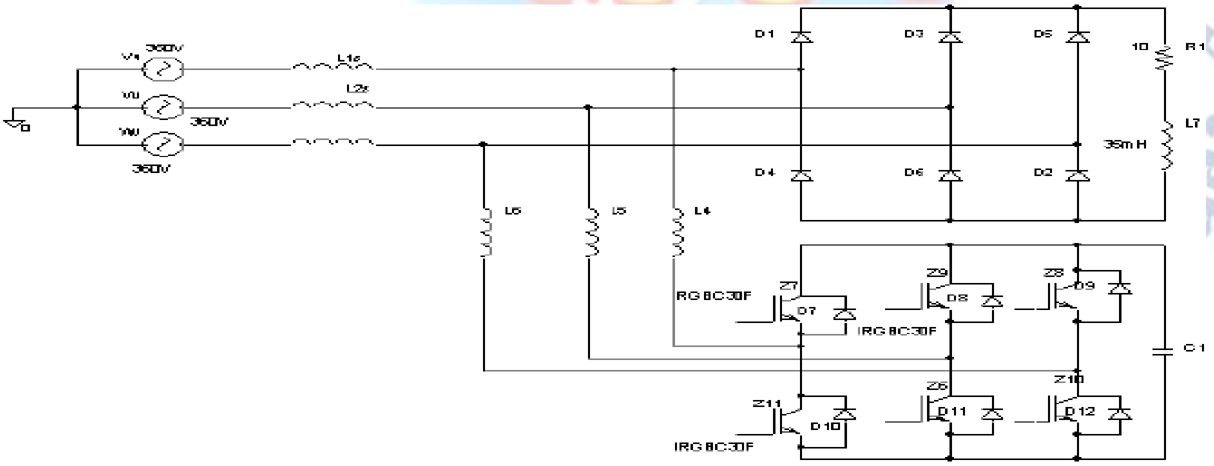

Fig .7 Configuration of the three phase, three wire Active filtering system.

Three aspects have to be considered in the design of APF.

1. The parameters of the inverter such as inverter switches and the values of the link inductances.
2. Modulation method used
3. The control method used to generate the harmonic reference template.

IV. PROPOSED UNIFIED POWER QUALITY CONDITIONER (UPQC)

The Unified Power Quality Conditioner (UPQC) is a more complete solution for the power quality problem. The basic structure of this equipment is shown in shown in Fig .4. In this figure, the UPQC is an association of a series and shunt active filter based on two converters with common dc link. The series converter has the function to compensate for the harmonic components (Including unbalances) present in the source voltages in such a way that the voltage on the load is sinusoidal and balanced.

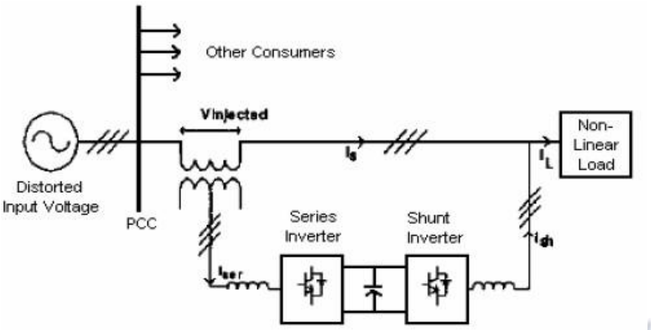

Fig .8 Basic Block Diagram of UPQC

The shunt active filter has the function of eliminating the harmonic components of nonlinear loads in such a way that the source current is sinusoidal and balanced. This equipment is a good solution for the case when the voltage source presents distortion and a harmonic sensitive load is close to a nonlinear load asshown in Fig8.To provide a balance, distortion-free, and constant magnitude power to sensitive load and, at the same time, to restrict the harmonic, unbalance, and reactive power demanded by the load and hence to make the overall power distribution system more healthy, the unified power quality conditioner (UPQC) is one of the best solutions. A unified power quality conditioner (UPQC) is a device that is similar in construction to a unified power flow conditioner (UPFC). The UPQC, like a UPFC, employs two voltage source inverters (VSIs) that are connected to a common dc energy storage capacitor. One of these two VSIs is connected in series with the ac line while the other is connected in the shunt with the same line. A UPFC is employed in a power transmission system to perform shunt and series compensation at the same time. Similarly a UPQC can also perform both the tasks in a power distribution system. A power distribution system, on the other hand, may contain unbalance, distortion and even dc components. Therefore a UPQC must operate under this environment while providing shunt or series compensation.

A. *UPQC Configurations*

Unified power quality conditioners are viable compensation devices that are used to ensure that delivered power meets all required standards and specifications at the point of installation.

The ideal UPQC can be represented as the combination of avoltage-source converter (injecting series voltage V_C), a current-source converter (injecting shunt current I_C), and a common DC link (connected to a DC capacitor). There are two possible ways of connecting the unit to the terminal voltage (V_t)at PCC

1. Right-shunt UPQC (Fig. 9a), where the shunt compensator (I_C) is placed at the right side of the series compensator (V_C).
2. Left-shunt UPQC (Fig. 9b), where the shunt compensator (I_C) is placed at the left side of the series compensator (V_C).

These two structures have similar features; however, the overall characteristics of the right shunt UPQC are superior (e.g., operation at zero power injection/absorption mode, achieving unity power factor at load terminals, and full reactive power compensation). In this chapter, a right-shunt UPQC configuration is assumed and analyzed.

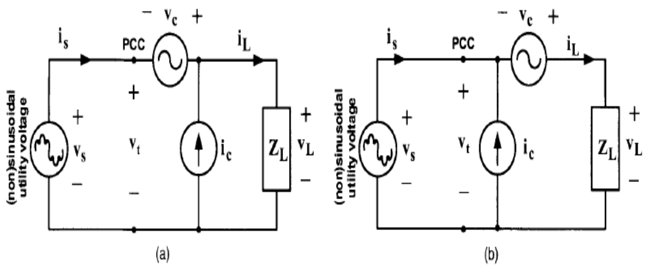

Fig. 9 Ideal UPQC Structure (a) the Right-Shunt UPQC (b) The Left-Shunt UPQC

V. 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.10 shows a 3P4W network in which the neutral conductor is provided from the generating station itself, where Fig. 11 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. 12.

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.

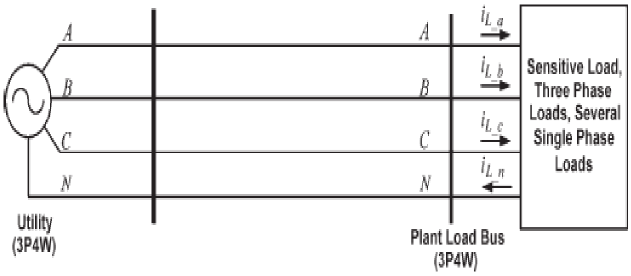

Fig. 10 3P4W distribution system: neutral provided from generation station

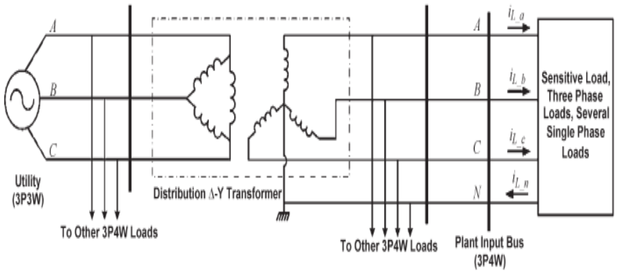

Fig. 11 3P4W distribution system: neutral provided from Δ-Y transformer

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. 12. This system has all the advantages of general UPQC, in addition to easy expansion of 3P3W system to 3P4W system. 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.

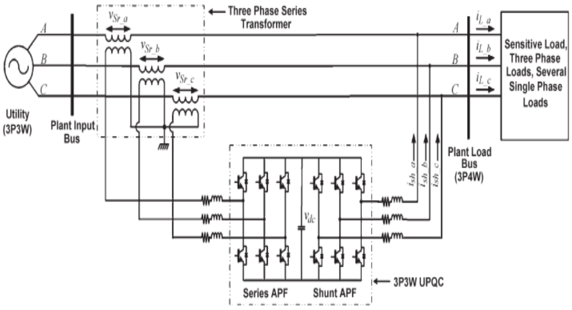

Fig. 12 3P3W UPQC structure

As shown in Fig. 12, 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. 13). The neutral current, present if any, would flow through this fourth wire toward transformer neutral point. Thefour-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.

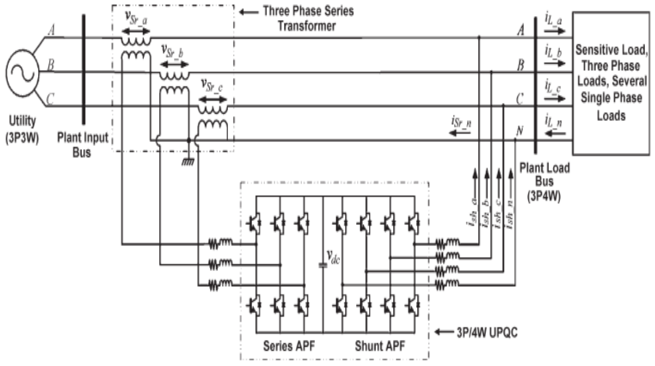

Fig. 13 3P4W UPQC structure

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.

VI. SIMULATION RESULTS

In this section UPQC, shunt VSC controller, series VSC controller, loads and series transformer blocks are implemented in MATLAB/SIMULINK and also explained in detail.

A. *Implementation of UPQC*

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. These three VSCs connected back to back through a common dc-link capacitor. Each of the VSCs in Fig. 14 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.

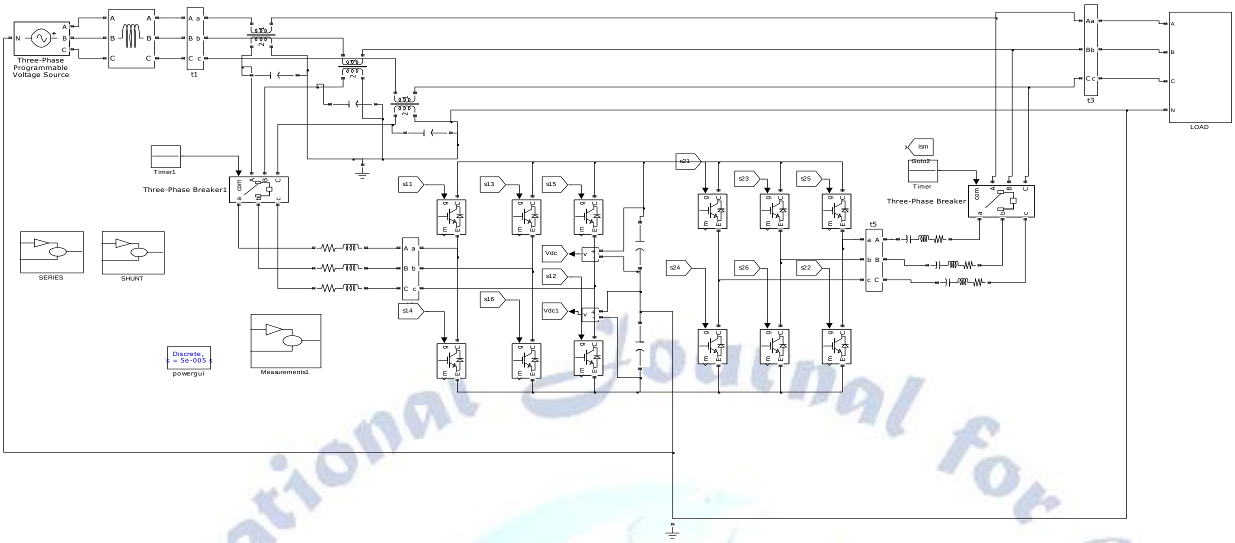

Fig14. Simulink block diagram of UPQC

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

B. Implementation of VSCs

The structure of VSC is shown in the Fig. 15

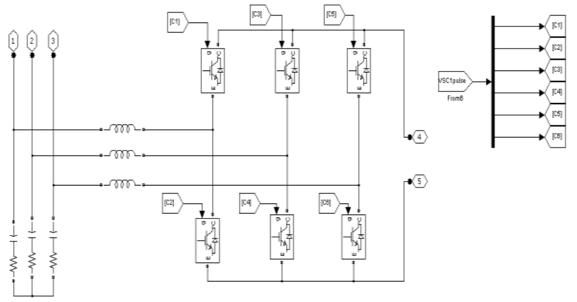

Fig. 15 Simulink block diagram of VSCs

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.

C. Implementation of Series Transformer

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

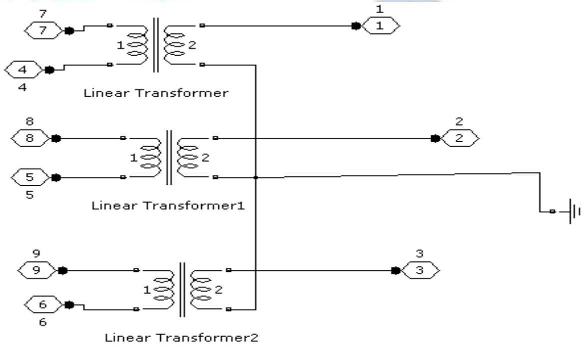

Fig. 16Simulink diagram of three-phase series transformer

D. Implementation of Shunt and Series Controllers

The Simulink block diagram of shunt controller is shown in the Fig. 17.

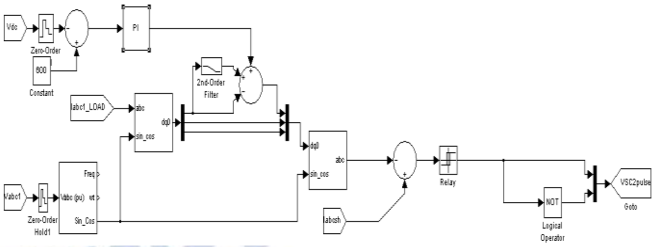

Fig. 17Simulink block diagram of shunt controller

transformed into the synchronous *dq*0 frame. A low pass filter is used to extract the harmonics. The PI contoller is used to regulate the dc-link capacitor voltage.

The Simulink block diagram of series controller is shown in the Fig. 7.9.

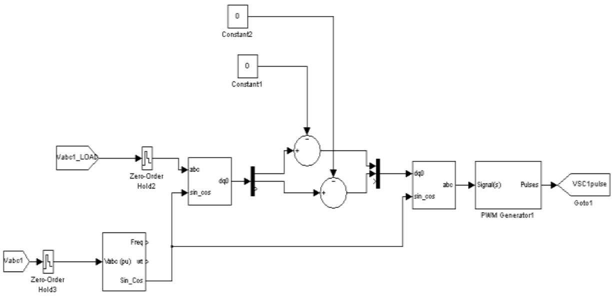

Fig. 18 Simulink block diagram of series controller

E. Simulation Results:

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-aload voltage (vla) are shown in Fig. From this figure, itis 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.

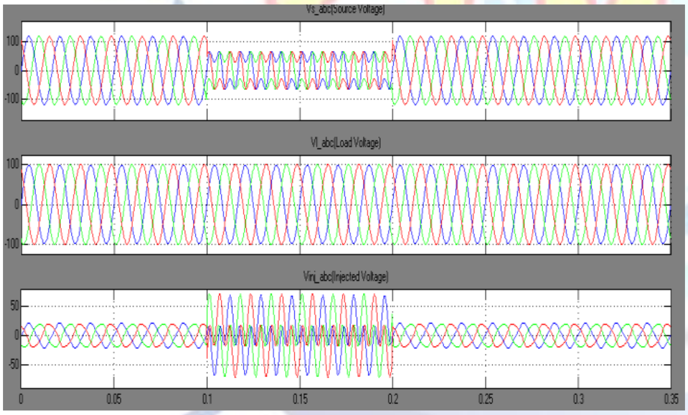

Fig 19: Simulation results using conventional topology. Terminal voltages with sag, DVR-injected voltages, and load voltages after compensation.

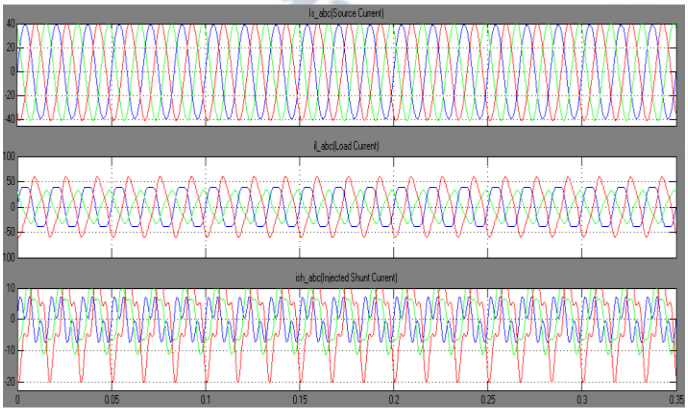

Fig 20: Simulation results using conventional topology. Shunt active filter currents

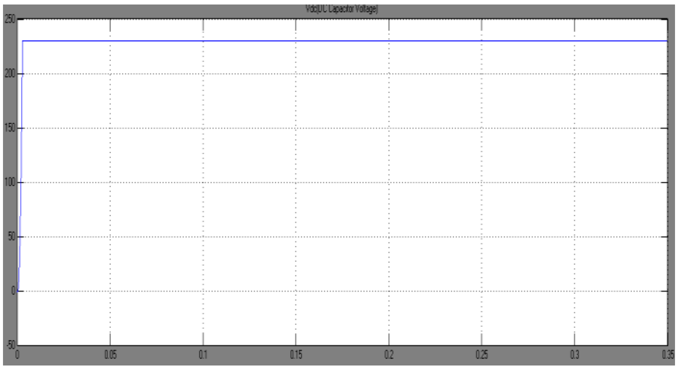

Fig 21: Simulation results using conventional topology. DC capacitor voltage

VII. 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 at 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

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