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Research Article

Simulation Study of UPQC and Active Power Filters for a Non-Linear Load

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Abstract

The application of power electronics devices such as arc furnaces, adjustable speed drives, computer power supplies etc. are some typical non-linear characteristic loads used in most of the industrial applications and are increasing rapidly due to technical improvements of semiconductor devices, digital controller and flexibility in controlling the power usage. The use of the above power electronic devices in power distribution system gives rise to harmonics and reactive power disturbances. The harmonics and reactive power cause a number of undesirable effects like heating, equipment damage and Electromagnetic Interference effects in the power system. The conventional method to mitigate the harmonics and reactive power compensation is by using passive LC filters but this method has drawbacks like large size, resonance problem and fixed compensation behaviour etc., so this solution becomes in effective. Subsequently, the active power filter (APF) comes in to the picture, which gives promising solution to compensate for the above adverse effects of harmonics and reactive power simultaneously by using suitable control algorithms.

Key words: *Active Power Filters (APF), Shunt Active Power Filter (SHF), Series Active Power Filter (SRF), Unified Power Quality Conditioner (UPQC),Voltage Source Inverter(VSI).*

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1. Introduction

With increasing applications of nonlinear and electronically switched devices in distribution systems and industries, power-quality (PQ) problems, such as harmonics, flicker, and imbalance have become serious concerns. In addition, lightning strikes on transmission lines, switching of capacitor banks, and various network faults can also cause PQ problems, such as transients, voltage sag/swell, and interruption. On the other hand, an increase of sensitive loads involving digital electronics and complex process controllers requires a pure sinusoidal supply voltage for proper load operation (Hirofumi Akagi, 1994).

In order to meet PQ standard limits, it may be necessary to include some sort of compensation. Modern solutions can be found in the form of active rectification or active filtering (Janko Nastran *et al* , 1994). A shunt active power filter is suitable for the suppression of negative load influence on the supply network, but if there are supply voltage imperfections, a series active power filter may be needed to provide full compensation (E. Destobbeleer *et al*, 1996). In recent years, solutions based on flexible ac transmission systems (FACTS) have appeared. The application of FACTS concepts in distribution systems has resulted in a new generation of compensating devices. A unified power-quality conditioner (UPQC) (Mauricio Aredes *et al*, 1996) is the extension of the unified power-flow controller (UPFC) (Hideaki Fujita *et al*, 1998) concept at the distribution level. It consists of combined series and shunt converters for simultaneous compensation of voltage and current imperfections in a supply feeder (Fang Zheng Peng *et al*, 1998; Kishore Chatterjee *et al*,1999; Po-Tai Cheng *et al*,1999).

Recently, multiconverter FACTS devices, such as an interline power-flow controller (IPFC) (Shyh-Jier Huang *et al*, 1999) and the generalized unified power-flow controller (GUPFC) (Ambrish Chandra *et al*, 2000) are introduced. The aim of these devices is to control the power flow of multilines or a subnetwork rather than control the power flow of a single line by, for instance, a UPFC.

When the power flows of two lines starting in one substation need to be controlled, an interline power flow controller (IPFC) can be used. An IPFC consists of two series VSCs whose dc capacitors are coupled. This allows active power to circulate between the VSCs. With this configuration, two lines can be controlled simultaneously to optimize the network utilization.

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The GUPFC combines three or more shunt and series converters. It extends the concept of voltage and power-flow control beyond what is achievable with the known two-converter UPFC. The simplest GUPFC consists of three converters—one connected in shunt and the other two in series with two transmission lines in a substation. The basic GUPFC can control total five power system quantities, such as a bus voltage and independent active and reactive power flows of two lines. The concept of GUPFC can be extended for more lines if necessary. The device may be installed in some central substations to manage power flows of multilines or a group of lines and provide voltage support as well. By using GUPFC devices, the transfer capability of transmission lines can be increased significantly.

Furthermore, by using the multiline-management capability of the GUPFC, active power flow on lines cannot only be increased, but also be decreased with respect to operating and market transaction requirements. In general, the GUPFC can be used to increase the transfer capability and relieve congestions in a flexible way. This concept can be extended to design multiconverter configurations for PQ improvement in adjacent feeders. For example, the interline unified power-quality conditioner (IUPQC), which is the extension of the IPFC concept at the distribution level, has been proposed in (Moleykutty George *et al*,2004). The IUPQC consists of one series and one shunt converter. It is connected between two feeders to regulate the bus voltage of one of the feeders, while regulating the voltage across a sensitive load in the other feeder. In this configuration, the voltage regulation in one of the feeders is performed by the shunt-VSC. However, since the source impedance is very low, a high amount of current would be needed to boost the bus voltage in case of a voltage sag/swell which is not feasible. It also has low dynamic performance because the dc-link capacitor voltage is not regulated(M. George, C.L. Seen *et al*, 2004; Hyosung Kim *et al* ,2004;J. G. Nielsen *et al* ,2004).

In this paper, a new configuration of a UPQC called the multiconverter unified power-quality conditioner (MC-UPQC) is presented. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations(E. K. K. Sng *et al*, 2004; M. J. Newman *et al* ,2005).

2. Power quality problems

The contemporary container crane industry, like many other industry segments, is often enamored by the bells and whistles, colorful diagnostic displays, high speed performance, and levels of automation that can be achieved. Although these features and their indirectly related computer based enhancements are key issues to an efficient terminal operation, we must not forget the foundation upon which we are building. Power quality is the mortar which bonds the foundation blocks. Power quality also affects terminal operating economics, crane reliability, our environment, and initial investment in power distribution systems to support new crane installations. To quote the utility company newsletter which accompanied the last monthly issue of my home utility billing: ‘Using electricity wisely is a good environmental and business practice which saves you money, reduces emissions from generating plants, and conserves our natural resources.’ As we are all aware, container crane performance requirements continue to increase at an astounding rate. Next generation container cranes, already in the bidding process, will require average power demands of 1500 to 2000 kW – almost double the total average demand three years ago. The rapid increase in power demand levels, an increase in container crane population, SCR converter crane drive retrofits and the large AC and DC drives needed to power and control these cranes will increase awareness of the power quality issue in the very near future.

2. Power Quality Problems

For the purpose of this article, we shall define power quality problems as:

‘Any power problem that results in failure of customer equipment, manifests itself as an economic burden to the user, or produces negative impacts on the environment.’

When applied to the container crane industry, the power issues which degrade power quality include:

- Power Factor
- Harmonic Distortion
- Voltage Transients
- Voltage Sags or Dips
- Voltage Swells

The AC and DC variable speed drives utilized on board container cranes are significant contributors to total harmonic current and voltage distortion. Whereas SCR phase control creates the desirable average power factor, DC SCR drives operate at less than this. In addition, line notching occurs when SCR’s commutate, creating transient peak recovery voltages that can be 3 to 4 times the nominal line voltage depending upon the system impedance and the size of the drives. The frequency and severity of these power system disturbances varies with the speed of the drive. Harmonic current injection by AC and DC drives will be highest when the drives are operating at slow speeds. Power factor will be lowest when DC drives are operating at slow speeds or during initial acceleration and deceleration periods, increasing to its maximum value when the SCR’s are phased on to produce rated or base speed. Above base speed, the power factor essentially remains constant. Unfortunately, container cranes can spend considerable time at low speeds as the operator attempts to spot and land containers. Poor power factor places a greater KVA demand burden on the utility or engine-alternator power source. Low power factor loads can also affect the voltage stability which can ultimately result in detrimental effects on the life of sensitive electronic equipment or even intermittent malfunction. Voltage transients created by DC drive SCR line notching, AC drive voltage chopping, and high frequency harmonic voltages and currents are all significant sources of noise and disturbance to sensitive electronic equipment

It has been our experience that end users often do not associate power quality problems with Container cranes, either because they are totally unaware of such issues or there was no economic Consequence if power quality was not addressed. Before the advent of solid-state power supplies, Power factor was reasonable, and harmonic current injection was minimal. Not until the crane Population multiplied, power demands per crane increased, and static power conversion became the way of life, did power quality issues begin to emerge. Even as harmonic distortion and power Factor issues surfaced, no one was really prepared. Even today, crane builders and electrical drive System vendors avoid the issue during competitive bidding for new cranes. Rather than focus on Awareness and understanding of the potential issues, the power quality issue is intentionally or unintentionally ignored. Power quality problem solutions are available. Although the solutions are not free, in most cases, they do represent a good return on investment. However, if power quality is not specified, it most likely will not be delivered.

Power quality can be improved through:

- Power factor correction,
- Harmonic filtering,
- Special line notch filtering,
- Transient voltage surge suppression,
- Proper earthing systems.

In most cases, the person specifying and/or buying a container crane may not be fully aware of the potential power quality issues. If this article accomplishes nothing else, we would hope to provide that awareness.

In many cases, those involved with specification and procurement of container cranes may not be cognizant of such issues, do not pay the utility billings, or consider it someone else’s concern. As a result, container crane specifications may not include definitive power quality criteria such as power factor correction and/or harmonic filtering. Also, many of those specifications which do require power quality equipment do not properly define the criteria. Early in the process of preparing the crane specification:

- Consult with the utility company to determine regulatory or contract requirements that must be satisfied, if any.
- Consult with the electrical drive suppliers and determine the power quality profiles that can be expected based on the drive sizes and technologies proposed for the specific project.
- Evaluate the economics of power quality correction not only on the present situation, but consider the impact of future utility deregulation and the future development plans for the terminal.

3. Shunt Active Power Filter

A shunt active power filter, with a self-controlled dc bus has a topology similar to that of a Static Compensator (STATCOM). The shunt active power filter compensate the load current by injecting equal but opposite harmonic compensating current, In this case the shunt active power filter acts as a current source injecting the harmonic components equal to that generated by the load but a phase shift of 180°.

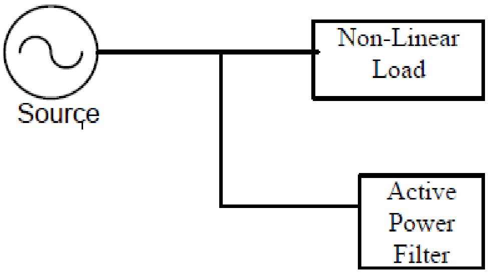

Fig 1 Basic Arrangement of Shunt Active Filter

3.1 MAT LAB Model of Shunt Active Power Filter

In the model, first the capacitor voltage is sensed and compared with the reference voltage, the error signal generated is then given to the controller to generate the reference current I_c which is then multiplied with unit vector template and then delayed or advanced by 120° to get the reference currents for the three phases a, b, c. These reference currents are now compared with the actual source currents; the error signal is now put in the hysteresis controller to generate the firing pulses for the inverter. The ON-OFF of the switches is dependent upon the error signal. The output of the filter is such that the source current is purely sinusoidal and harmonic content is drawn or supplied by the filter.

3.2 Simulation Result for Shunt Active Power Filter

Figure 3(a) shows MAT LAB Simulation Result of Voltage and Current without SHF with Load voltage 100v (peak) And Load current 0.08amp for a Time period of 1sec.The upper part of the figure shows load voltage and the lower part of the figure shows load current.

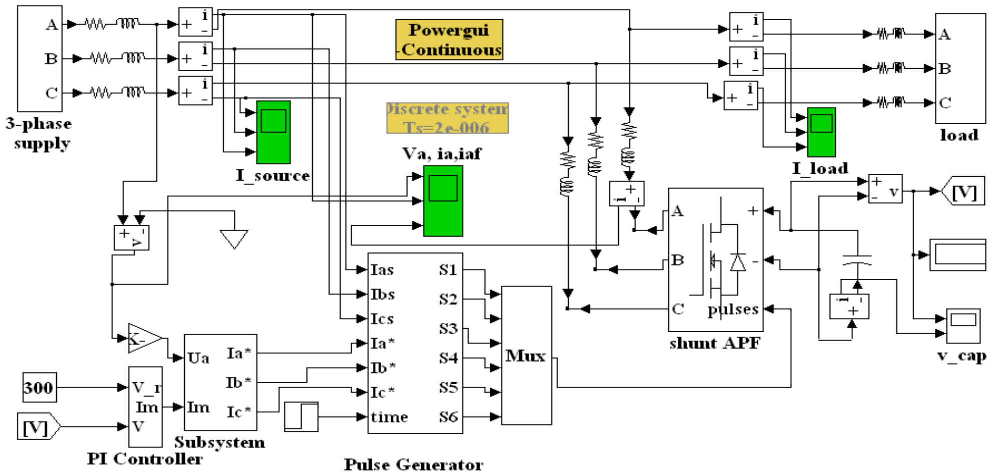

Fig 2 MAT LAB Model for Shunt Active Power Filter

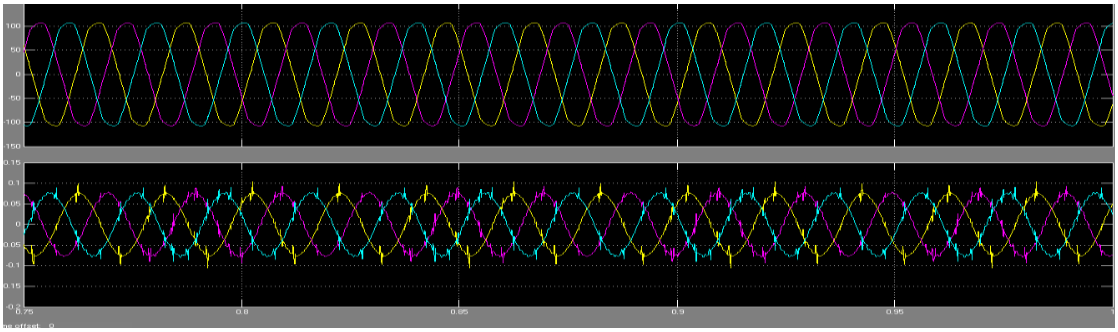

Fig 3(a) Voltage & current waveforms with load (without filter)

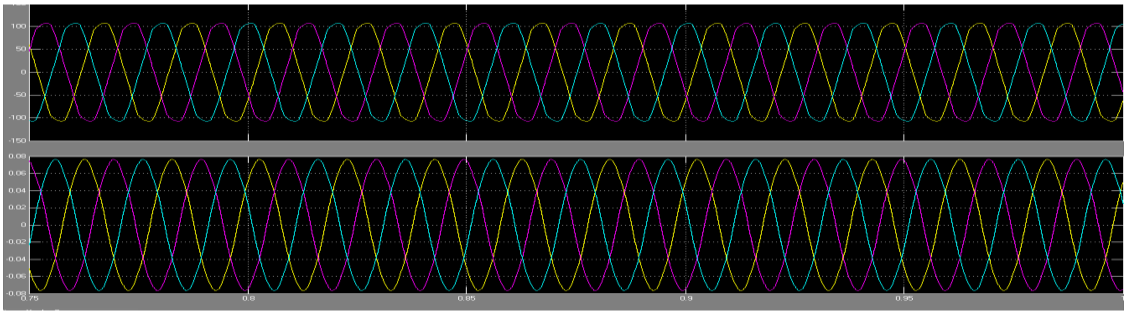

Fig 3(b) Voltage & current waveforms with load (with filter)

Figure 3(b) shows MAT LAB Simulation Result of Voltage and Current with SHF with Load voltage 100v (peak) And Load current 0.08amp for a Time period of 1sec.The upper part of the figure shows load voltage and the lower part of the figure shows load current.

Reduction of distortion in the voltage and current waveforms are observed in fig 3(b) which occurred in 3(a)

4. Series Active Power Filter

The excessive use of the semiconductor switching equipment in the industrial applications has resulted in the degradation of the power quality. The increase in the nonlinear loading has also added to this problem by the factors such as harmonic increase, power factor degradation. Although, the passive filters have been in use for a long time but a large number of passive filters would be required for a bandwidth to remove the harmonics, which may again cause a hazard of the resonance with the source impedance.

A Voltage Source Inverter (VSI) is used as a Series Active Power Filter and is used to draw or inject a Vc i.e. a compensating voltage from or to the supply, such that it cancels the voltage harmonics on the load side.

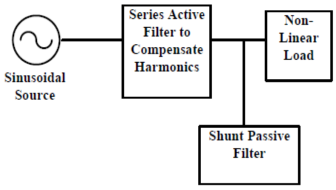

Fig 4 Base arrangement of Series Active Power Filter

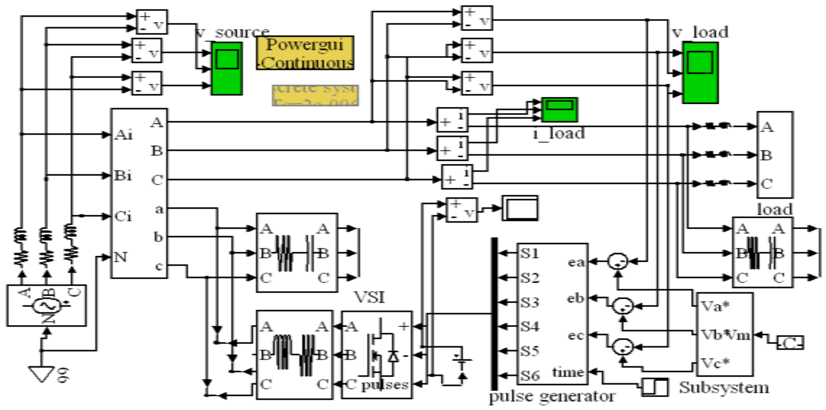

Fig 5 MAT LAB model of Series Active Power Filter

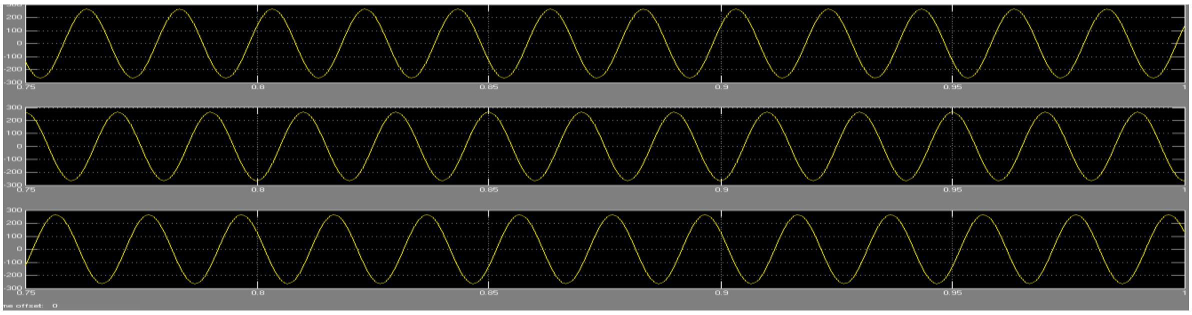

Fig 6(a) Series APF (Voltage wave forms)

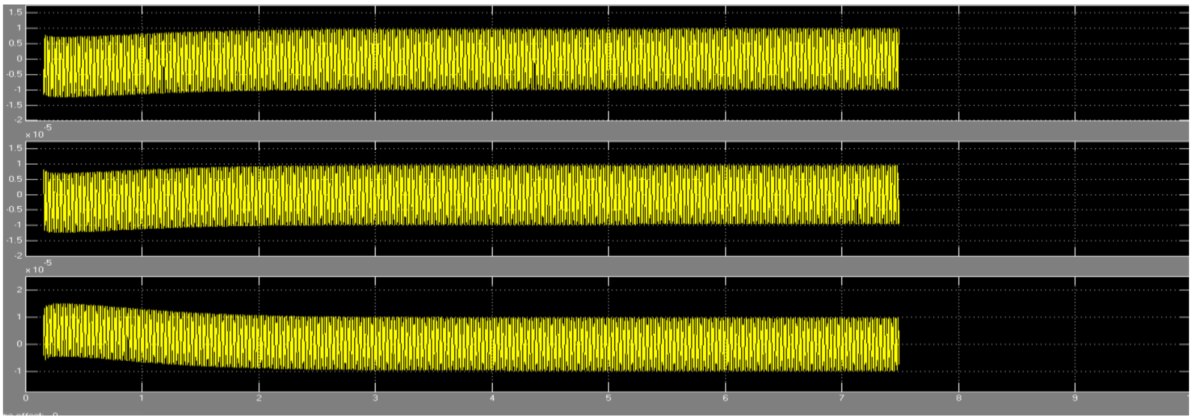

Fig 6(b) Current wave forms without Series APF (Amplitude in Ampere)

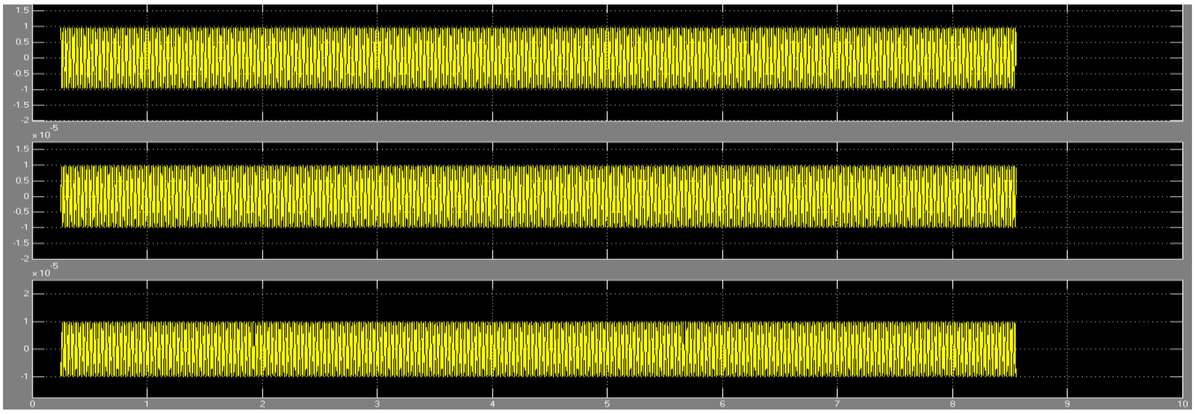

Fig 6(c) Current wave forms with Series APF (Amplitude in Ampere)

Table 1 Comparison between Linear and Non-Linear Loads

Sl. No	Linear loads	Non-Linear Loads
1	Examples; Power Factor Improvement Capacitor, Heaters, Incandescent Lamps etc.	Examples; Computer, Laser Printer, SMPs, Rectifier, Refrigerator etc.
2	Ohms law is valid	Ohms law is not valid
3	Load current does not contain harmonics	Load current contains all odd harmonics.
4	Could be inductive or capacitive.	Can't be categorized as leading or lagging loads.
5	Zero neutral current, if 1-Phase loads are equally balanced on 3-Phase Mains (Vector sum of line current)	Even if single phase loads are equally balanced on 3-phase neutral current could be 2.7 times the line current.
6	May not demand high inrush currents while starting.	Essentially very high inrush current (20 time of Normal) is drawn while starting for approximant One cycle.

4.1 MAT LAB model of Series Active Power Filter

The Fig 5 shows the MATLAB Model of the Series Active Power Filter. The operation can be explained as – After the generation of the reference voltages they are compared with the load voltages and the error signal is then sent to the hysteresis controller to generate the firing pulses for the inverter switches. ON-OFF of the switches is dependent upon this error signal. The output of the power filter is fed to the main lines through the series transformers so as to make the load voltage purely sinusoidal by absorbing or injecting the harmonic voltage.

4.2 Simulation Result For Series Active Power Filter

Fig 6(a) Shows MAT LAB Simulation of the Series APF (Voltage wave forms) with load voltage 200v (peak) for a time period of 1 second.

Fig 6(b) Shows the MAT LAB Simulation Current wave forms without Series APF with load voltage 200v(peak) for a time period of 10 seconds in three phase where topmost waveform $I_a = 0.5\times10^{(-5)}$, middle waveform $I_b = 0.6\times10^{(-5)}$, bottom waveform $I_c = 1.5\times10^{(-5)}$.

Fig 6(c) Shows the MAT LAB Simulation Current wave forms with Series APF with load voltage 200v(peak) for a time period of 10 seconds in three phase where all current waveforms having magnitude $I = 1\times10^{(-5)}$ amp.

5. Linear and Non Linear Loads

5.1 Linear Loads

AC electrical loads where the voltage and current waveforms are sinusoidal and the current at any time proportional to voltage are treated as linear loads. If pure sinusoidal voltage is passed through the resistive element, then the shape of the current wave form will be purely sinusoidal without distortion. Voltage and current waveform in a circuit involving inductor make voltage lead current. On the other hand for a circuit involving capacitor, current leads voltage.

5.2 Non-Linear Loads

AC loads where the current is not proportional to the voltage are considered as nonlinear loads. Non-linear loads generate harmonics in the current waveform that leads to distortion of the voltage waveform; under these conditions the voltage is no longer proportional to the current. The table below shows the examples of linear and non-linear loads and comparison between them.

The Simulink model of a variable load torque DC machine arrangement is shown in Fig 7. The model consists of a three phase rectifier which converts AC supply to DC which then excites the DC machine.

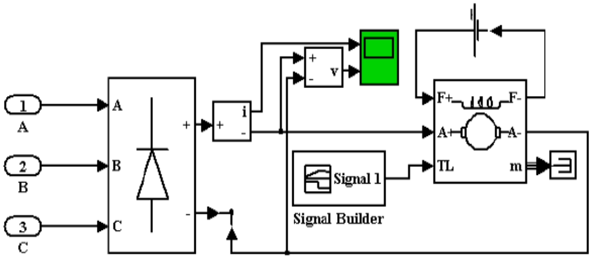

Fig 7 DC machine with variable load torque

6. Classifications of Active Power Filters

6.1 Converter based classification

Current Source Inverter (CSI) Active Power Filter Fig 8(a) and Voltage Source Inverter Active Power Filter (VSI) Fig 8(b) 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 8(b). 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.

6.2 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 8(c) 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.

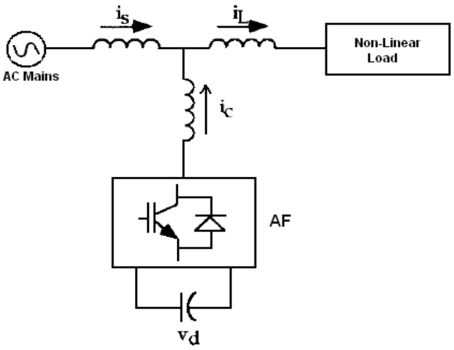

Fig 8(a) Current fed type AF

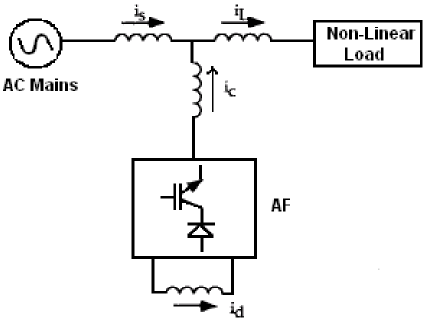

Fig 8(b) Voltage fed type AF

Fig 8(d) 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 8(e) 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.

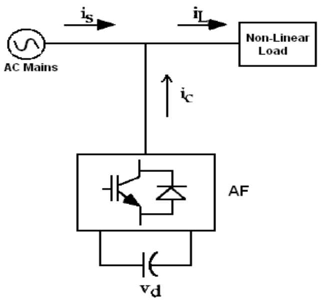

Fig 8(c) Shunt-type AF

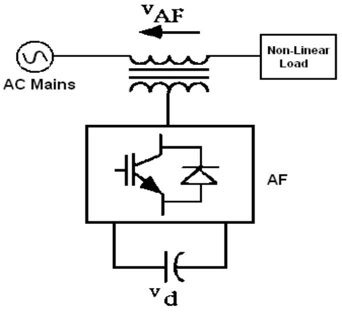

Fig 8(d) Series-type AF

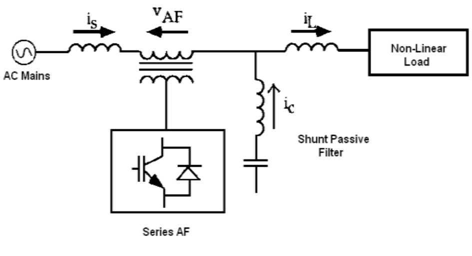

Fig 8(e) Hybrid filter

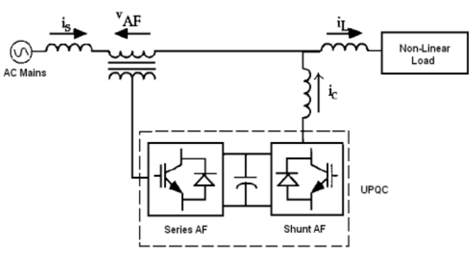

Fig 8(f) Unified Power Quality Conditioner

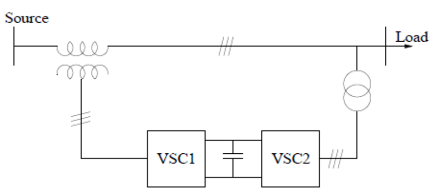

Fig 9(a) Basic Arrangement of UPQC

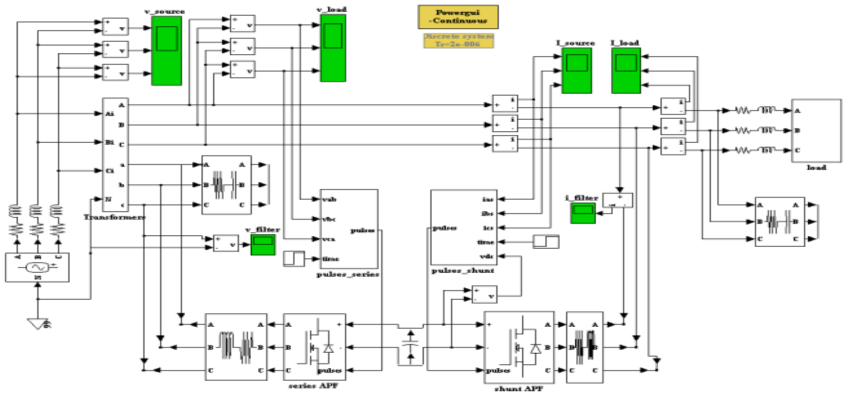

Fig 9(b) MATLAB Model of UPQC

Fig 8(f) 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.

7. Unified Power Quality Conditioner (UPQC)

The provision of both DSTATCOM and DVR can control the power quality of the source current and the load bus voltage. In addition, if the DVR and STATCOM are connected on the DC side, the DC bus voltage can be regulated by the shunt connected DSTATCOM while the DVR supplies the required energy to the load in case of the transient disturbances in source voltage. The configuration of such a device (termed as Unified Power Quality Conditioner (UPQC)) is shown in Fig. This is a versatile device similar to a UPFC. However, the control objectives of a UPQC are quite different from that of a UPFC.

7.1 Control Objectives of UPQC

The shunt connected converter has the following control objectives

1. To balance the source currents by injecting negative and zero sequence components required by the load
2. The compensate for the harmonics in the load current by injecting the required harmonic currents
3. To control the power factor by injecting the required reactive current (at fundamental frequency)
4. To regulate the DC bus voltage.

The series connected converter has the following control objectives

1. To balance the voltages at the load bus by injecting negative and zero sequence voltages to compensate for those present in the source.
2. To isolate the load bus from harmonics present in the source voltages, by injecting the harmonic voltages
3. To regulate the magnitude of the load bus voltage by injecting the required active and reactive components (at fundamental frequency) depending on the power factor on the source side.
4. To control the power factor at the input port of the UPQC (where the source is connected. Note that the power factor at the output port of the UPQC (connected to the load) is controlled by the shunt converter.

7.2 MATLAB Model of Unified Power Quality Conditioner

The Fig 9(b) shows the MATLAB model of the Unified Power Quality Conditioner (UPQC). first the reference voltages and the reference currents are generated and then the reference voltages are compared with the actual load voltages and the reference currents are compared with the actual source currents and then the error signals are given to the hysteresis controllers for generating the switching signals for the switches of series active power filter and the shunt active power filter. And the generated pulses are then given to the series and shunt APF's and accordingly the switches are turned on and off to compensate for the voltage and current harmonics.

7.3 Response of UPQC with a Non-Linear Load

The Variable Torque DC machine is taken as the load; the responses are observed and then the FFT (Fast Fourier Transform) analysis is done of the signals to determine the Total Harmonic Distortion (THD). The load voltage which acts as the input to the DC machine arrangement, before and after compensation is shown in Fig 10; as clearly observed in Fig 10(a) that as the pulse is generated at 0.15 seconds the harmonic content in the load voltage reduces. The zoom in view of the selected area of fig.10 (a) is shown in fig. 10(b).

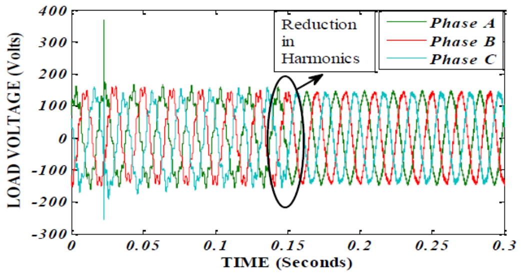

Fig 10(a)

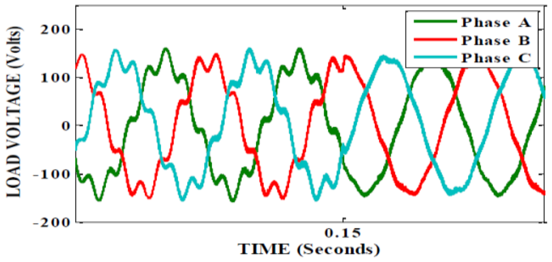

Fig 10(b)

Fig 10 Load Voltage before and after compensation

The compensating filter voltage of the phase 'A' which is to reduce the nonlinearities on the load side voltage is shown in the Fig. 11.we observe the nonlinearities starting at 0.15 sec which opposes the voltage nonlinearities on the load side.

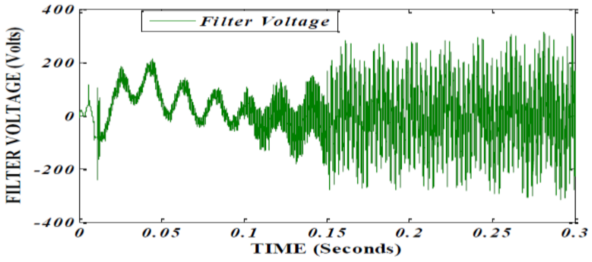

Fig 11 Compensating Voltage for Phase 'A'

The load current acting as the supply to DC Machine arrangement contains a lot of harmonics is shown in the Fig 12.

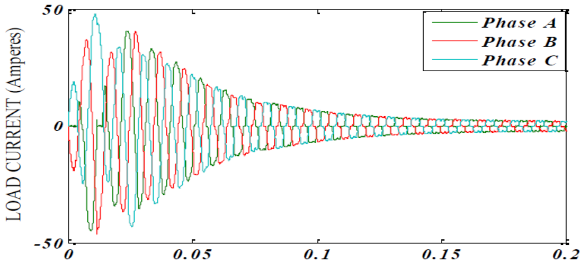

Fig 12 Load Current

The compensating filter current of the phase 'A' which is to reduce the nonlinearities of the source current is shown in the Fig 14; we observe the nonlinearities starting at 0.1 sec which opposes the current nonlinearities on the source side. Zoom in view of selected area fig. 13(a) is shown in fig13(b).

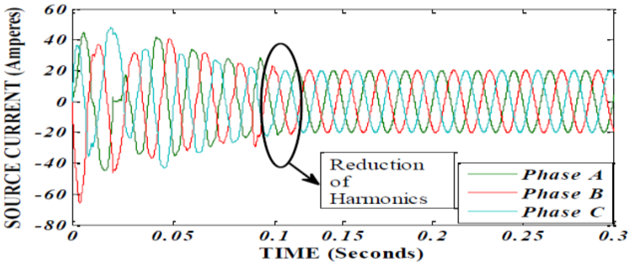

Fig 13 (a)

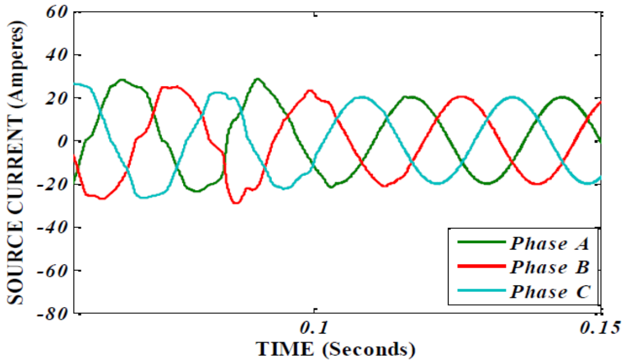

Fig 13(b)

Fig 13 Source Current Before and After Compensation

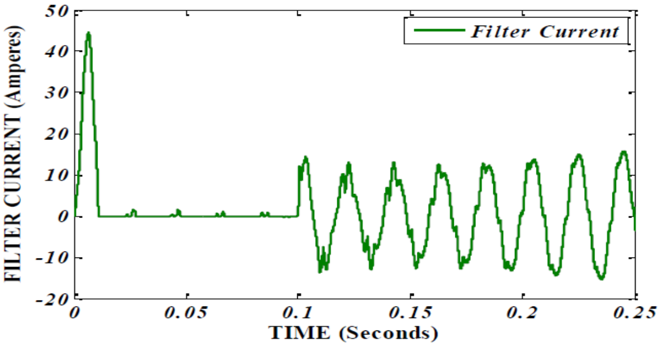

Fig. 14 Compensating Current for the Phase 'A'

Conclusion

Custom power devices like 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 (PI) and simulated results have been described which establishes the fact that in both the cases the compensation is done but the response of.

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