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Causes, Effects and Solutions of Poor Quality Problems in the Power Systems

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Abstract

The term electric power quality broadly refers to maintaining a nearly sinusoidal power distribution bus voltage at rated magnitude and frequency. In addition, the energy supplied to a consumer must be uninterrupted from reliability point of view. Though power quality is mainly a distribution system problem, power transmission system may also have impact on quality of power. With the ever-increasing use of sophisticated controls and equipment in industrial, commercial, institutional, and governmental facilities, the continuity, reliability, and quality of electrical service has become extremely crucial to many power users. Electrical systems are subject to a wide variety of power quality problems which can interrupt production processes, affect sensitive equipment, and cause downtime, scrap, and capacity losses. Momentary voltage fluctuations can disastrously impact production. . . extended outages have a greater impact.

Key Words: Power Systems, Shunt Active Filter, Series Active Filter and Shunt Series Active Filter etc…

I. INTRODUCTION

The power system networks are continuously expanding over wide geographical area with increased number of interconnection to meet the rapid growth in the demand of electricity. The transmission and distribution networks are main carriers of electrical power.

The present power distribution system is usually configured as a three-phase three-wire or four-wire structure featuring a power-limit voltage source with significant source impedance, and an aggregation of various types of loads. Ideally, the system should provide a balanced and pure sinusoidal three-phase voltage of constant amplitude to the loads; and the loads should draw a current from the line with unity power factor, zero harmonics, and balanced phases. To four-wire systems, no excessive neutral current should exist. As a result, the maximum power capacity and efficiency of the energy delivery are achieved, minimum perturbation to other appliances is ensured, and safe operation is warranted. However, with a fast increasing number of applications of industry electronics connected to the distribution systems today, including nonlinear, switching, reactive, single-phase and unbalanced three-phase loads, a complex problem of power quality evolved characterized by the voltage and current harmonics, unbalances, low Power Factor (PF).

In recent years active methods for power quality control have become more attractive compared with passive ones due to their fast response, smaller size and higher performance. For example, Static VAR Compensator (SVC) has been reported to improve the power factor; Power Factor Corrector (PFC) and Active Power Filters (APF) have the ability of current harmonics suppression and power factor correction; some active circuits were developed to compensate unbalanced currents as well as limit the neutral current. In general, parallel-connected converters have the ability to improve the current quality while the series-connected regulators inserted between the load and the supply, improve the voltage quality. For voltage and current quality control, both series and shunt converters are necessary, which is known as Unified Power Quality Conditioner (UPQC).

II. POWER SYSTEM STABILITY

The ability of an electric power system, operating at a given initial operating condition, to regain a state of operating equilibrium after being subjected to a disturbance, with most system variables bounded so that practically the entire system remains intact.

The power system stability can be broadly classified into three types.

- Rotor angle stability
- Frequency stability
- Voltage stability

Frequency and voltage stability can be further categorized into short term and long term stability.

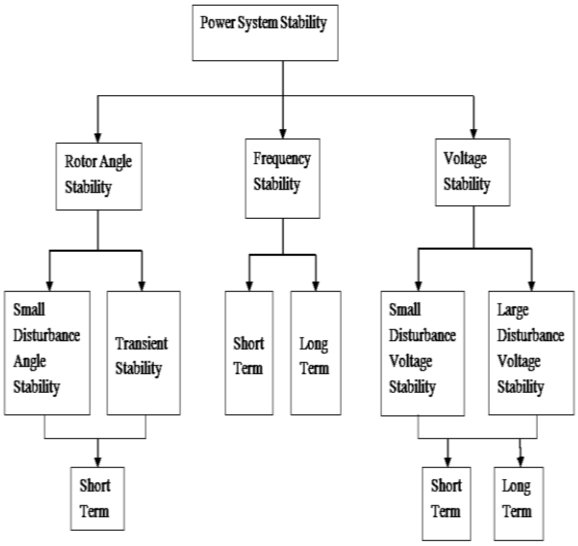


Fig-1: Classification of Power System Stability

III. POWER QUALITY PROBLEMS

I. Voltage Sags

Sags are a short-term reduction in voltage (that is 80-85% of normal voltage). Sags are most often caused by fuse or breaker operation, motor starting, or capacitor switching. Voltage sags typically are non-repetitive, or repeat only a few times due to recloses operation.

Fig-2 : Waveform of Voltage Sags

II. Power Interruptions

Power interruptions are zero-voltage events and are typically short duration events, the vast majority of power interruptions are less than 30 seconds.

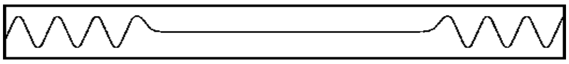


Fig-3 : Waveform of Power Interruptions

III. Voltage Flicker

Voltage flicker is rapidly occurring voltage sags caused by sudden and large increases in load current. Voltage flicker is most commonly caused by rapidly varying loads that require a large amount of reactive power

Fig-4 : Waveform of Voltage Flicker

IV. Power Surges

A power surge takes place when the voltage is 110% or more above normal. The most common cause is heavy electrical equipment being turned off.

V. High-Voltage Spikes

High-voltage spikes occur when there is a sudden voltage peak of up to 6,000 volts. These spikes are usually the result of nearby lightning strikes, but there can be other causes as well.

VI. Switching Transients

Switching transients take place when there is an extremely rapid voltage peak of up to 20,000 volts with duration of 10 microseconds to 100 microseconds. Switching transients take place in such a short duration that they often do not show up on normal electrical test equipment. They are commonly caused by machinery starting and stopping, arcing faults and static discharge.

VII. Frequency Variation

A frequency variation involves a change in frequency from the normally stable utility frequency of 50Hz.This may be caused by erratic operation of emergency generators or unstable frequency power sources.

VIII. Electrical Line Noise

Electrical line noise is defined as Radio Frequency Interference (RFI) and Electromagnetic Interference (EMI) and causes unwanted effects in the circuits of computer systems.

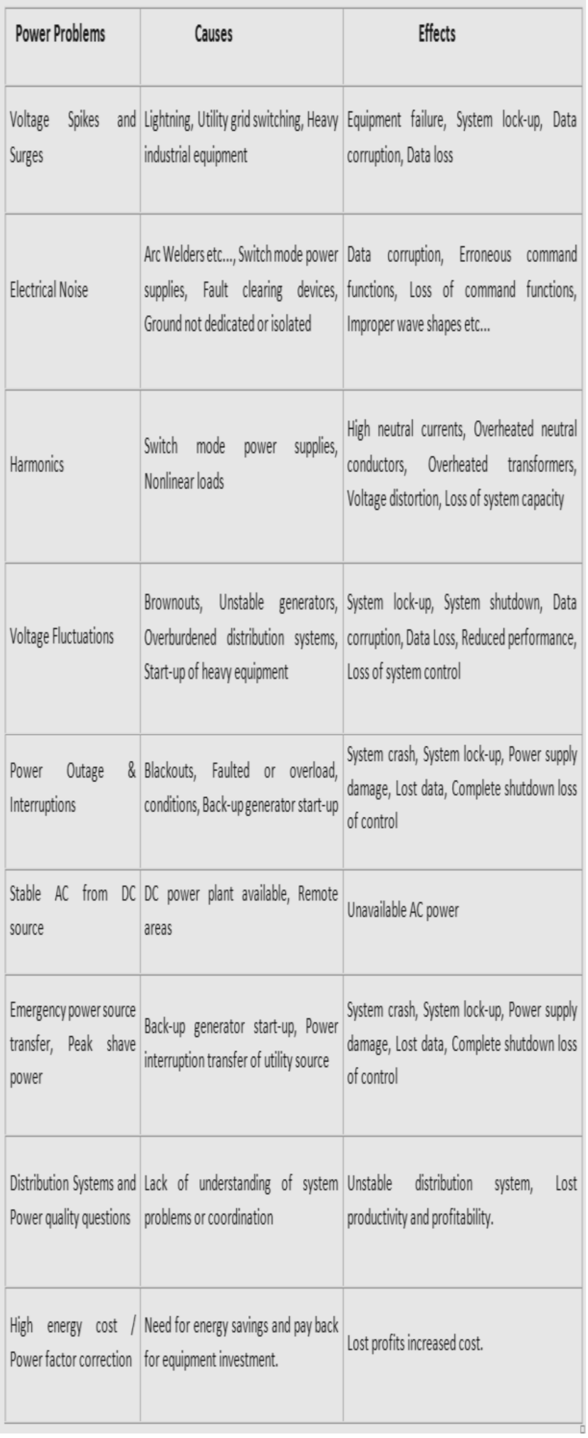
IX. Brownouts

A brownout is a steady lower voltage state. An example of a brownout is what happens during peak electrical demand in the summer, when utilities can't always meet the requirements and must lower the voltage to limit maximum power. When this happens, systems can experience glitches, data loss and equipment failure.

X. Blackouts

A power failure or blackout is a zero-voltage condition that lasts for more than two cycles. It may be caused by tripping a circuit breaker, power distribution failure or utility power failure. A blackout can cause data loss or corruption and equipment damage.

Many power quality problems are easily identified once a good description of the problems is obtained. A power quality audit can help determine the causes of one’s problems and provide a well-designed plan to correct them. The power quality audit checks one’s facility's wiring and grounding to ensure that it is adequate for one’s applications and up to code.



Power Problems	Causes	Effects
Voltage Spikes and Surges	Lightning, Utility grid switching, Heavy industrial equipment	Equipment failure, System lock-up, Data corruption, Data loss
Electrical Noise	Arc Welders etc..., Switch mode power supplies, Fault clearing devices, Ground not dedicated or isolated	Data corruption, Erroneous command functions, Loss of command functions, Improper wave shapes etc...
Harmonics	Switch mode power supplies, Nonlinear loads	High neutral currents, Overheated neutral conductors, Overheated transformers, Voltage distortion, Loss of system capacity
Voltage Fluctuations	Brownouts, Unstable generators, Overburdened distribution systems, Start-up of heavy equipment	System lock-up, System shutdown, Data corruption, Data Loss, Reduced performance, Loss of system control
Power Outage & Interruptions	Blackouts, Faulted or overload, conditions, Back-up generator start-up	System crash, System lock-up, Power supply damage, Lost data, Complete shutdown loss of control
Stable AC from DC source	DC power plant available, Remote areas	Unavailable AC power
Emergency power source transfer, Peak shave power	Back-up generator start-up, Power interruption transfer of utility source	System crash, System lock-up, Power supply damage, Lost data, Complete shutdown loss of control
Distribution Systems and Power quality questions	Lack of understanding of system problems or coordination	Unstable distribution system, Lost productivity and profitability.
High energy cost / Power factor correction	Need for energy savings and pay back for equipment investment.	Lost profits increased cost.

Table-1 : Causes and Effects of Power Problems

The voltage quality may contain amplitude errors, harmonics, phase unbalance, sag/dips, swells, flicks, impulses and interrupt voltage. As a whole these problems can be listed as given in table2.

Voltage quality problems

	Duration	Existing forms
Steady state	>3s	Under-voltage; over voltage; outage; unbalance; harmonics
Momentary	10ms-3s	Sag/dip; swell; interrupt
Transient	<10ms	Flick; impulse; e.g. switching and fault transients

Table-2: Voltage quality problems

As far as the current quality is concerned harmonics, reactive component, unbalance, excessive neutral zero-sequence current are the main issues. As a whole these problems can be listed as given in table3.

Current quality problems

Three phase load	Reactive (inductive/capacitive)	Reactive power
	Non-linear	Harmonics
	Switching	Common-mode noise
	Unbalanced	Excessive neutral/zero sequence current
Single phase (line-neutral or line-line)	Reactive (inductive/capacitive)	Excessive neutral/zero sequence current
	Non-linear Harmonics	
	Switching Common-mode noise/EMI	

Table-3: Current quality problems

IV. Power Quality Solutions

Protecting power quality is a big business right now. There are many choices of equipment and manufacturers. The most expensive solution is not always the right solution for the problem. Both correct identification of the power problems our company's needs should be addressed to ensure an accurate assessment.

There are five basic categories of solutions to some of the power quality problems, each having different capabilities, strengths and weaknesses.

1) Surge Suppressors
2) Voltage Regulators
3) Power Conditioners
4) Uninterruptable Power Supplies
5) Generators

4.1 Surge Suppressors

A surge suppressor is often used to shield important, but less critical or highly sensitive equipment. It is also used as a complement to more comprehensive power protection solutions. They are passive electronic devices that protect against transient high-level voltages. However, low frequency surges (slow changes at 400 Hz or less) can be too great for a surge suppressor attempting to clamp that surge.

4.2 Voltage Regulators / Power Conditioners

A voltage regulator may also be referred to by the labels “power conditioner”, “line conditioner”, “voltage stabilizer”, etc. Regardless the term used, these devices are all essentially the same in that they provide voltage regulation and one or more additional power quality-related functions.

A voltage regulator can correct and/or provide protection from power problems such as:

I. Over / Under voltage
II. Voltage Fluctuations
III. Sags and Dips
IV. Line Noise and Swells
V. Phase Imbalance
VI. Short Circuits
VII. Brownouts and Surges

4.3 Uninterruptable Power Supplies (UPS)

There are three basic types of UPS.

I. Standby (or Offline)
II. Line Interactive
III. Double Conversion (or Online)

4.3.1 Standby (or Offline)

The Standby UPS consists of a basic battery/power conversion circuit and a switch that senses irregularities in the electric utility. The equipment to be protected is usually directly connected to the primary power source, and the power protection is available only when line voltage dips to the point of creating an outage. Some off-line UPS include surge protection circuits to increase the level of protection they offer.

4.3.2 Line Interactive

Line Interactive UPS are hybrid devices that offer a higher level of performance by adding better voltage regulation and filtering features to the standby UPS design.

4.3.3 Double Conversion (or Online)

Double conversion UPS, often called "Online" provide the highest level of power protection and are an ideal choice for shielding by our organization's most important computing and equipment installations. This technology uses the combination of a double conversion (AC to DC/DC to AC) power circuit and an inverter, which continuously powers the load to provide both conditioned electrical power and outage protection.

4.4 Generators

Generators are machines that convert mechanical energy into electrical energy. They are usually used as a backup power source for a facility's critical systems such as elevators and emergency lighting in case of blackout. However, they do not offer protection against utility power problems such as overvoltage and frequency fluctuations, and although most can be equipped with automatic switching mechanisms, the electrical supply is interrupted before switching is completed, so it cannot protect against the damage that blackouts can cause to expensive equipment and machinery.

If you use a generator to backup to a UPS during extended blackouts, the U.S. Department of Commerce suggests that it be rated at about 2½ times higher than the UPS it is backing up.

V. Active Power Filter

There are many solutions to power quality problems. But the most emerging solutions are active power filters.

1) Shunt Active Power Filter
2) Series Active Power Filter
3) Shunt-Series Active Power Filter (Unified Power Quality Conditioner – UPQC)

5.1 Shunt Active Power Filter

The shunt active power filter, with a self controlled dc bus, has a topology similar to that of a static compensator (STATCOM) used for reactive power compensation in power transmission systems. Shunt active power filters compensate load current harmonics by injecting equal but opposite harmonic compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180^o. Fig.5 shows the connection of a shunt active power filter and Fig.6 shows how active power filter works to compensate the load harmonic currents.

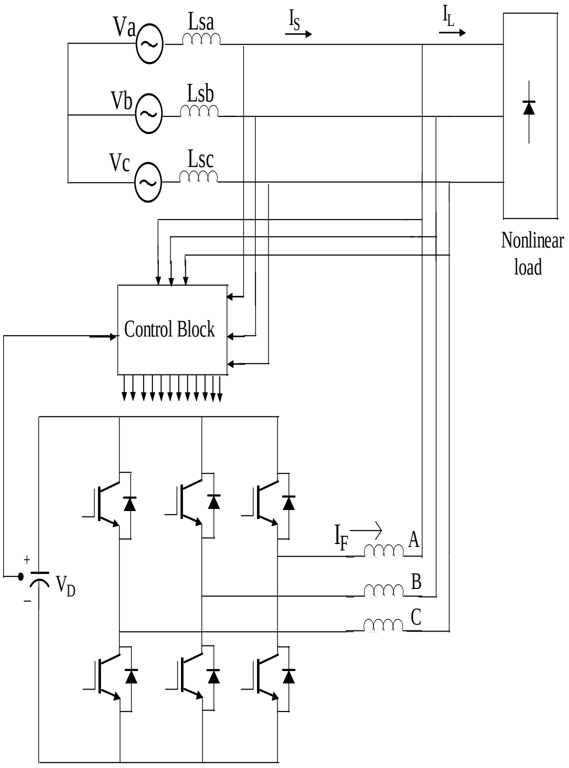


Fig-5: Shunt power filter topology

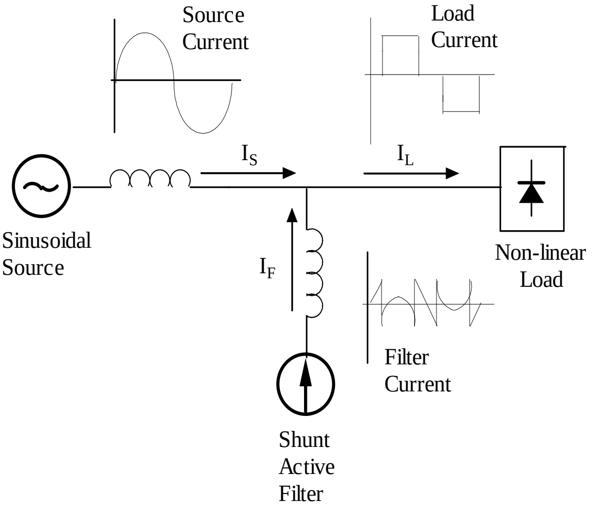


Fig-6: Filter current I_F generated to compensate load current harmonics

Basic compensation principle

Fig.7 (a) shows the basic compensation principle of shunt active power filter. A voltage source inverter (VSI) is used as the shunt active power filter. This is controlled so as to draw or supply a compensating current I_c from or to the utility, such that it cancels current harmonics on the AC side i.e. this active power filter (APF) generates the nonlinearities opposite to the load nonlinearities. Fig.7 (b) shows the different waveforms i.e. the load current, desired source current and the compensating current injected by the shunt active power filter which contains all the harmonics, to make the source current purely sinusoidal. This is the basic principle of shunt active power filter to eliminate the current harmonics and to compensate the reactive power.

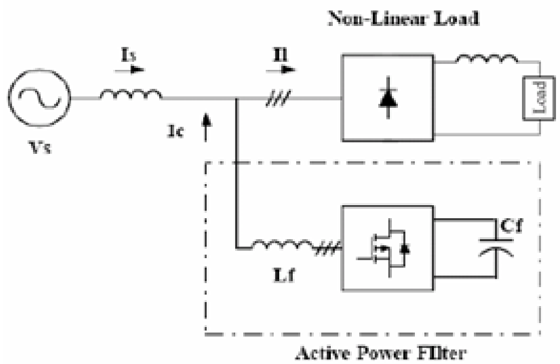


Fig-7(a): Basic compensation principle

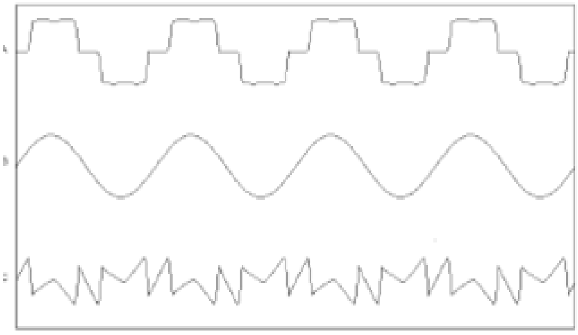


Fig-7 (b): Waveforms for the Actual Load Current (A), Desired Source Current (B) and Compensating Current (filter current- C)

5.2 Series Active Power Filter

Series active power filters were introduced to operate mainly as a voltage regulator and as a harmonic isolator between the nonlinear load and the utility system. The series connected filter protects the consumer from an inadequate supply voltage quality. This type of approach is especially recommended for compensation of voltage unbalances and voltage sags from the ac supply and for low power applications and represents economically attractive alternatives to UPS, since no energy storage (battery) is necessary and the overall rating of the components is smaller. The series active filter injects a voltage component in series with the supply voltage and therefore can be regarded as a controlled voltage source, compensating voltage sags and swells on the load side. In many cases, the series active filters work as hybrid topologies with passive LC filters. If passive LC filters are connected in parallel to the load, the series active power filter operates as a harmonic isolator, forcing the load current harmonics to circulate mainly through the passive filter rather than the power distribution system.

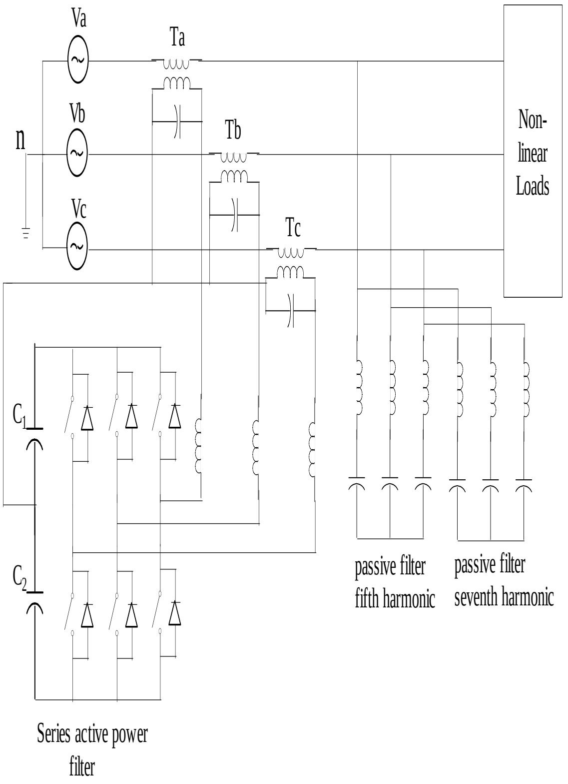


Fig-8: Series active power filter topology with shunt passive filters

The main advantage of this scheme is that the rated power of the series active filter is a small fraction of the load kVA rating, typically 5%. However, the apparent power rating of the series active power filter may increase in case of voltage compensation. Fig.8 shows the connection of a series active power filter, and Fig.9 shows how the series active filter works to compensate the voltage harmonics on the load side. Series filters can also be useful for fundamental voltage disturbances. The series filter during an occasional supply voltage drop keeps the load voltage almost constant and only small instabilities and oscillations are observed during initial and final edges of disturbance.

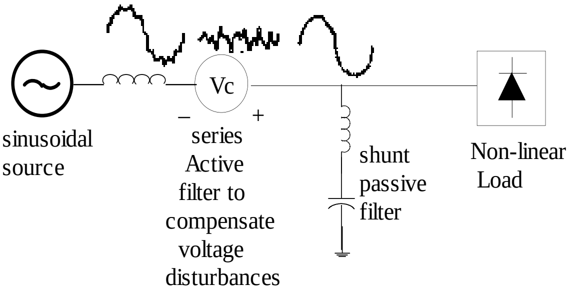


Fig-9: Filter voltage generation to compensate voltage disturbances

Basic compensation principle

Fig.10 (a) shows the basic compensation principle of series active power filters. A voltage source inverter (VSI) is used as the series active power filter. This is controlled so as to draw or inject a compensating voltage V_c from or to the supply, such that it cancels voltage harmonics on the load side i.e. this active power filter (APF) generates the distortions opposite to the supply harmonics. Fig.10 (b) shows the different waveforms i.e. source voltage, desired load voltage and the compensating voltage injected by the series active power filter which contains all the harmonics, to make the load voltage purely sinusoidal. This is the basic principle of series active power filter to eliminate the supply voltage harmonics.

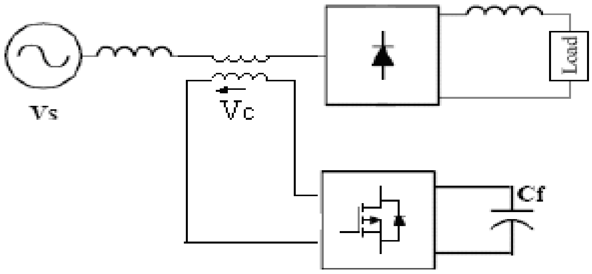


Fig-10 (a): Basic compensation principle

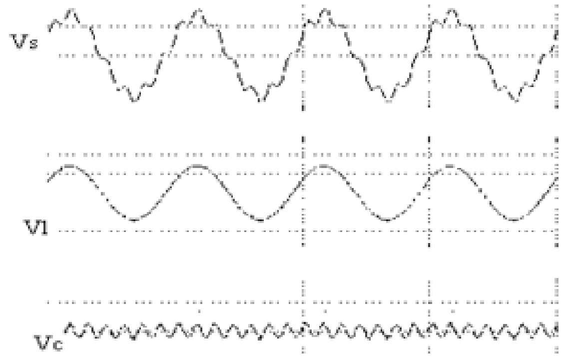


Fig-10 (b): Waveforms for the Supply Voltage (Vs), Desired Load Voltage (VI) and Compensating Voltage (filter voltage- Vc)

5.3 Shunt-Series Active Power Filter (UPQC)

As the name suggests, the shunt-series active power filter is a combination of series active power filter and shunt active power filter. The topology is shown in Fig.11 The shunt-active filter is located at the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology is called as Unified Power Quality Conditioner. The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter and damps power system oscillations. The shunt portion compensates load current harmonics, reactive power and load current unbalances. In addition, it regulates the dc link capacitor voltage. The power supplied or absorbed by the shunt portion is the power required by the series compensator and the power required to cover losses.

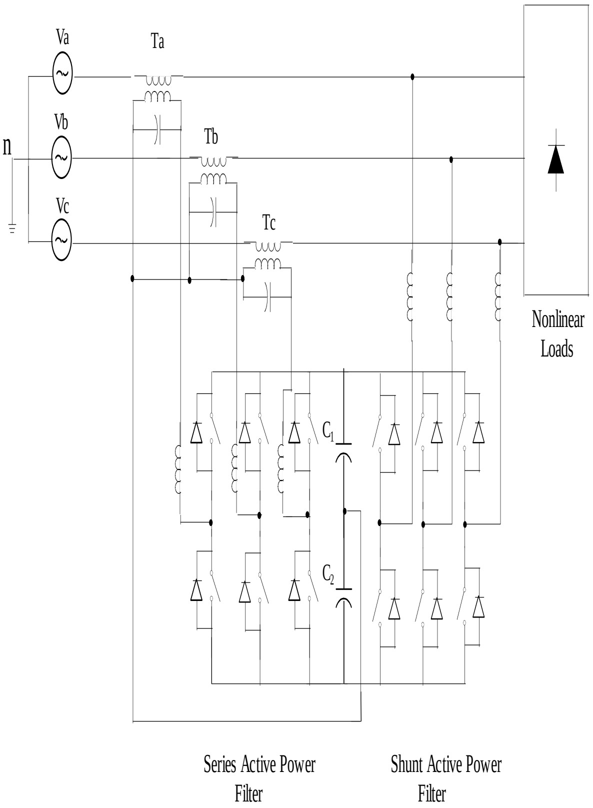


Fig-11: Unified power quality conditioner topology

General UPQC

Fig.12 shows the basic configuration of a general UPQC consisting of the combination of a series active and shunt active filter.

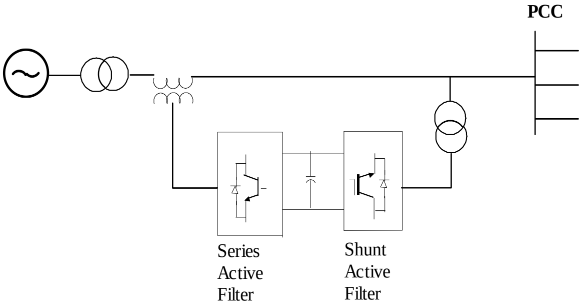


Fig-12: General UPQC

The main purpose of the series active filter is harmonic isolation between a sub transmission system and a distribution system. In addition the series active filter has the capability of voltage flicker/imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). The main purpose of the shunt active filter is to absorb current harmonics, compensate for reactive power and negative sequence current, and regulate the dc link voltage between both active filters.

VI. CONCLUSIONS

With a fast increasing number of applications of industry electronics connected to the distribution systems today, including nonlinear, switching, reactive, single-phase and unbalanced three-phase loads, a complex problem of power quality evolved characterized by the voltage and current harmonics, unbalances, low Power Factor (PF).

In this paper various power quality problems and the available solutions have been discussed briefly while the shunt APF, series APF and the unified power quality conditioner (UPQC), which consists of series and shunt active filters, have been discussed in detail. The Shunt APF has been used for compensating the source current harmonics. The Series APF has been used for compensating the load voltage harmonics. Whereas, the UPQC which has been used for compensating the source current and the load voltage harmonics simultaneously. Hence, the UPQC can be used for improving the power quality effectively.

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BIOGRAPHIES

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