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A Review of Power Quality Improvements by using FACTS devices

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--**ABSTRACT**--

In a recent trend for controlling of most of the industrial loads is mainly based on semiconductor devices which cause such loads to be more sensitive against power system disturbances. Thus, the power quality problems have gained more interest recently. This paper presents a review of some of the disturbances, on the source side that may cause problems on the load side. The focus is given on problems associated with voltage dips as voltage dips have been reported to be the most severe problems to industrial loads.

The power quality has an important role in the power supply industry. As the power providers are turning to smart grid and smart meters, the standards for power quality needs to be revisited. The power quality can be categorized into two groups, one addressing the standard for the power quality supplied at the grid level and the other group which deals with the factors that affect the power quality at user level. These factors include harmonics, voltage changes, sags, transients, voltage unbalance, etc. These factors will provide us in-depth details about the power system network. In this paper, an overview of various factors will be presented in order which can affect the power quality of the system.

KEYWORDS;- *Power quality, Flexible AC transmission system (FACTS) devices, UPFC, SVC, STATCOM.*

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I. INTRODUCTION

Utilities aim to provide their customers with an ideal sinusoidal voltage waveform. By definition, ideal sinusoidal voltage waveform has the characteristics: constant magnitude at the required level, constant frequency and balance in case of three phase operation. Naturally, this is not always possible because of normal system variations and due to the unavoidable incidents that temporarily can affect the operation, such as short-circuits faults. On the other hand, utilities require that customers should draw sinusoidal current. **S**OLID-STATE control of AC power using thyristors and other semiconductor switches is widely employed to feed controlled electric power to electrical loads, such as adjustable speed drives (ASD's), furnaces, computer power supplies, etc. Such controllers are also used in HVDC systems and renewable electrical power generation. As nonlinear loads, these solid-state converters draw harmonic and reactive power components of current from ac mains. In three-phase systems, they could also cause unbalance and draw excessive neutral currents. The injected harmonics, reactive power burden, unbalance, and excessive neutral currents cause low system efficiency and poor power factor. They also cause disturbance to other consumers and interference in nearby communication networks.

Power quality is always assumed that it is an ideal power supply which can give the options of voltage and system design to the user enabling him to utilize power from distribution system without any disturbance or interference. IEEE provides an alternate definition "Power Quality is defined as setting up standards for electrical equipment regarding their grounding and powering. These standards are useful for the operation of the electrical equipment, and also are compatible with wiring system and other connected equipment". These conditions can give rise to Power Quality issues which can be difference in voltage, surge in power, voltage and power sags are observed. A very simple approach could be developed to determine what power quality is, it is the precision of features and parameter defined in the system[4]. Power quality problems can be resolved in the power system by using FACTS devices for protecting the sensitive loads in the power system.

In the last two decades, power demand has increased substantially while the expansion of power generation and transmission has been severely limited due to limited resources and environmental restrictions. As a consequence, some transmission lines are heavily loaded and the system stability becomes a power transfer-limiting factor. Flexible AC transmission systems (FACTS) controllers have been mainly used for solving various power system steady state control problems. Flexible AC transmission systems or FACTS are devices which allow the flexible and dynamic control of power systems. Enhancement of system stability using FACTS controllers has been investigated. This paper is aimed towards the benefits of utilizing FACTS devices with the purpose of improving the operation of an electrical power system. Performance comparison of different FACTS controllers has been discussed. In addition, some of the utility experience and semiconductor technology development have been reviewed and summarized. Applications of FACTS to power system studies have also been discussed**.**

DISCUSSION OF DIFFERENT TYPES OF POWER QUALITY ISSUES [1]

Perfect power quality means the nature of voltage is continuous and almost purely sinusoidal with constant amplitude and frequency. The quality of the power can be expressed in the terms of the physical characteristics and properties of the electricity. Some of these describes as follow:-

- Voltage stability
- Frequency stability
- Electromagnetic interference effects
- Phase balance
- Telephone interference factors

The power quality issues in a power system network are generally due to voltage, frequency and interruption in the network. There may be any problem in it but it affects the output power. Generally the main source of poor power quality is voltage variation in the network.

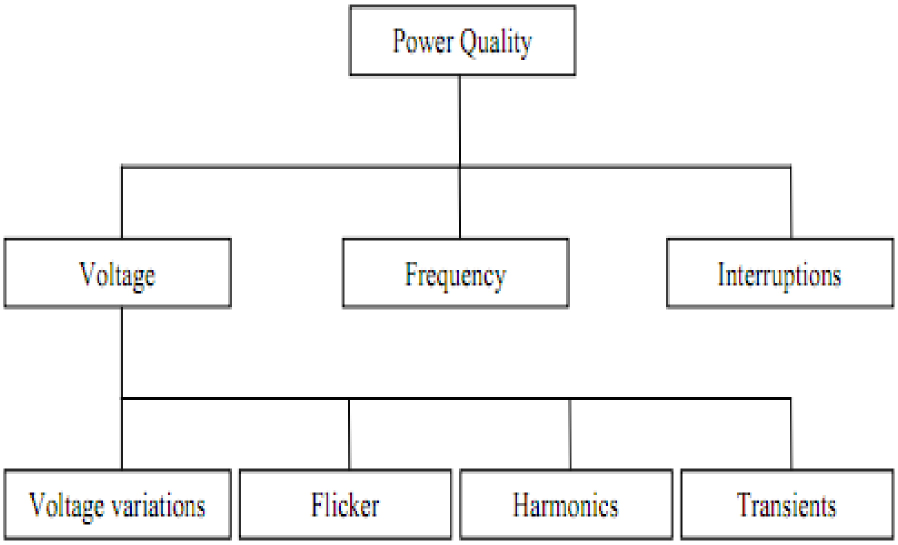

Figure: 1 – Different Types of Power Quality Issues

A. Description, Causes and Consequences

The most common types of Power Quality problems are presented below along with their description, causes and consequences:

1. Voltage sag (or dip)
2. Very short interruptions
3. Long interruptions
4. Voltage spike
5. Voltage swell
6. Harmonic distortion
7. Voltage fluctuation
8. Noise
9. Voltage Unbalance

1. Voltage sag(or dip)

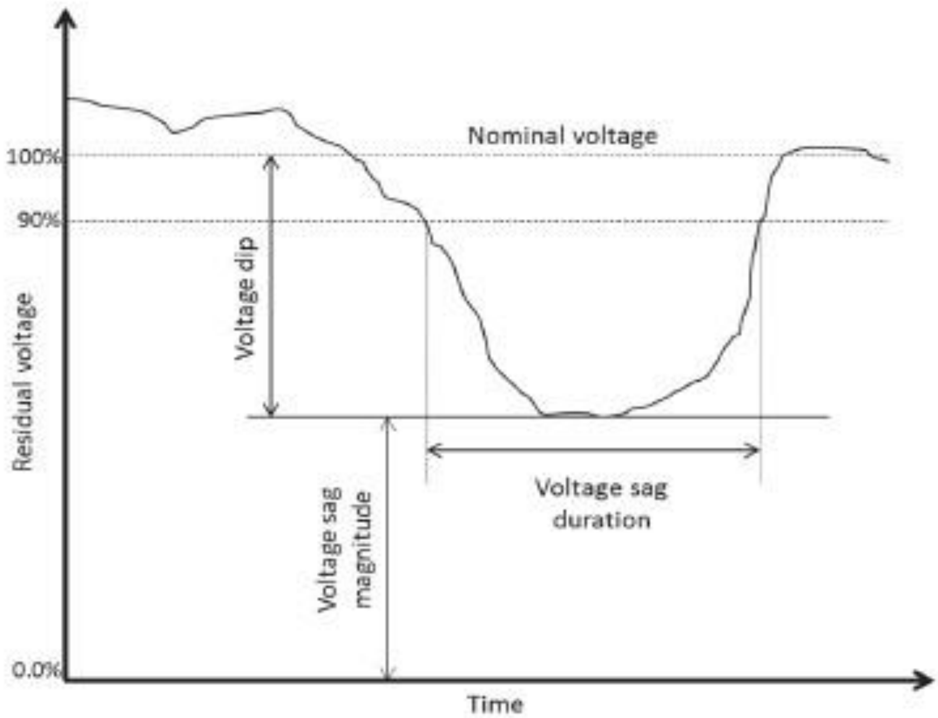

Figure: 2 – Characteristics of Voltage Sag[9]

Description: A decrease of the normal voltage level between **10% and 90%** of the nominal rms voltage at the power frequency, for durations of 0-5 cycle to 1 minute.

Causes: Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors.

Consequences: Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc.) that may lead to a process stoppage. Tripping of contactors and electromechanical relays. Disconnection and loss of efficiency in electric rotating machines.

2. Very short interruptions

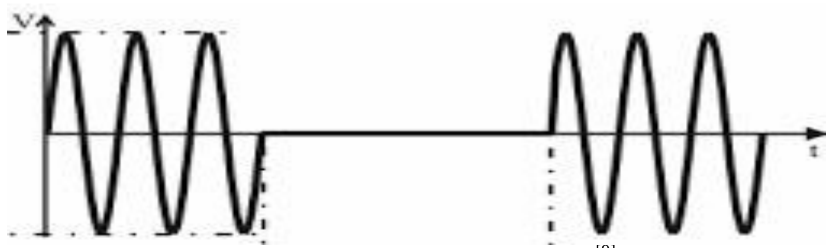

Figure: 3 – Very Short Interruption[9]

Description : Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes: Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.

Consequences: Tripping of protection devices, loss of information and malfunction of data processing equipment. Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they are not prepared to deal with this situation.

3. Long interruptions

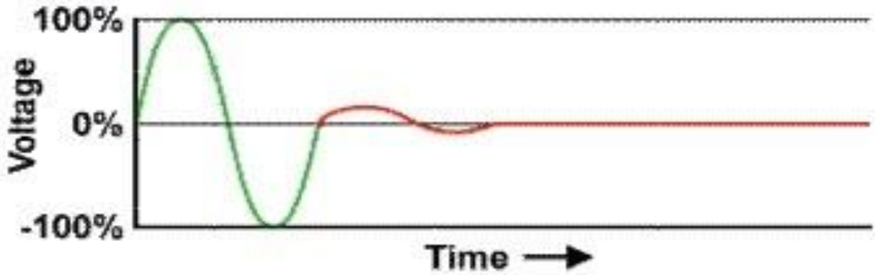

Figure: 4 – Long Voltage Interruption[9]

Description: Total interruption of electrical supply for duration greater than 1 to 2 seconds

Causes: Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices.

Consequences: Stoppage of all equipment.

4. Voltage spike

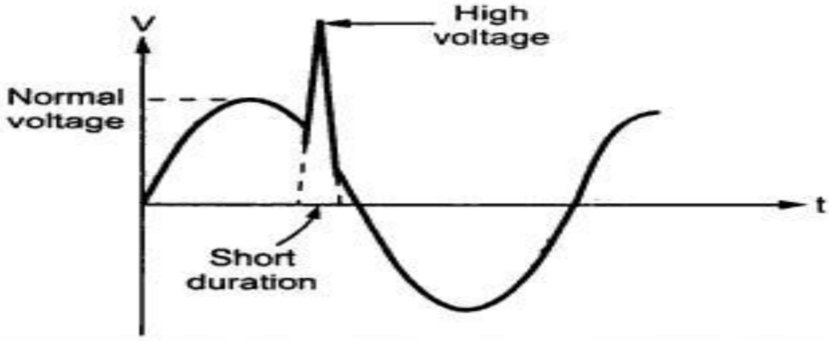

Figure: 5 – Characteristics of Voltage Spike[9]

Description: Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

Causes: Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads.

Consequences: Destruction of components (particularly electronic components) and of insulation materials, data processing errors or data loss, electromagnetic interference.

5. Voltage swell

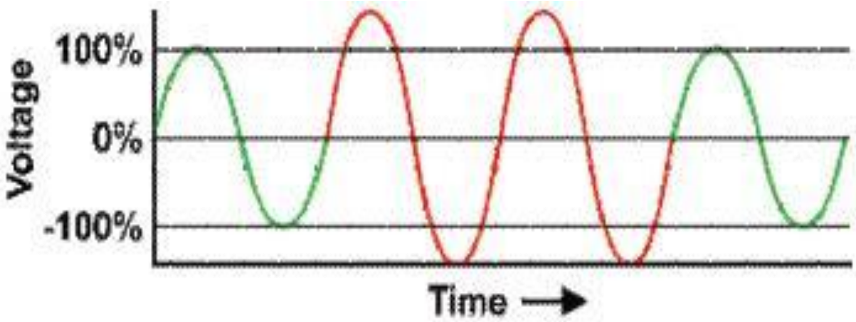

Figure: 6 – Voltage Swell [9]

Description: Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds.

Causes: Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours).

Consequences: Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.

6. Harmonic distortion

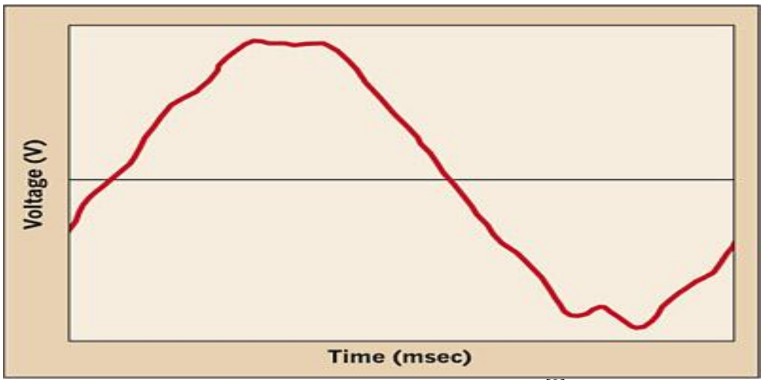

Figure: 7 – Harmonic Distortion[9]

Description: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency.

Causes: Classic sources: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers and converters used in power system network at different locations.

Modern sources: All non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

Consequences: Neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, errors in measures when using average reading meters, nuisance tripping of thermal protections. Increased probability in occurrence of resonance.

7. Voltage fluctuation

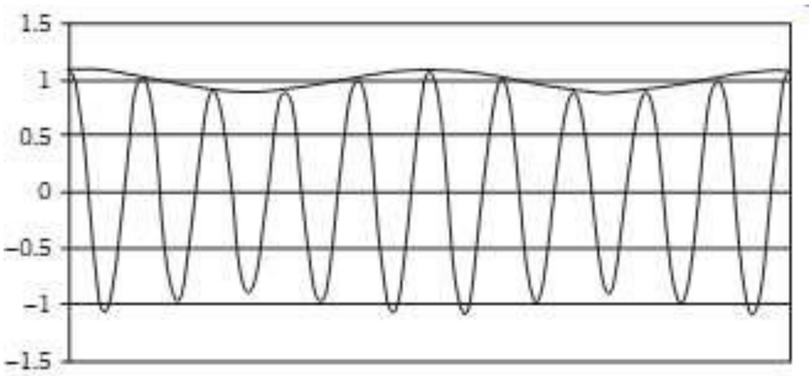

Figure: 8 – Voltage Fluctuation[9]

Description: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.
Causes: Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.
Consequences: Most consequences are common to under voltages. The most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

8. Noise

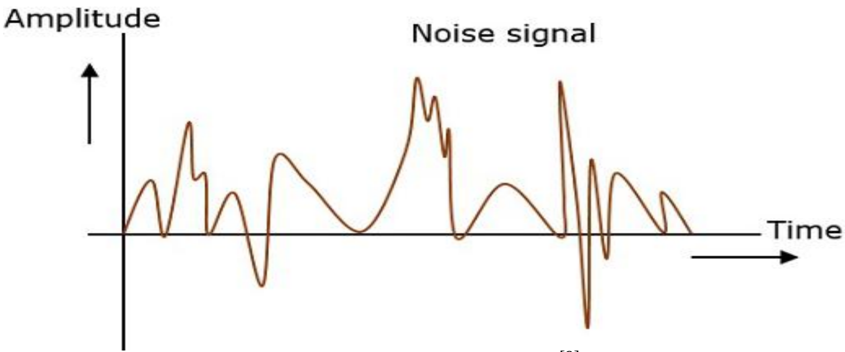

Figure: 10 – Noise Signal [9]

Description: Superimposing of high frequency signals on the waveform of the power-system frequency.
Causes: Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.
Consequences: Disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors.

9. Voltage unbalance

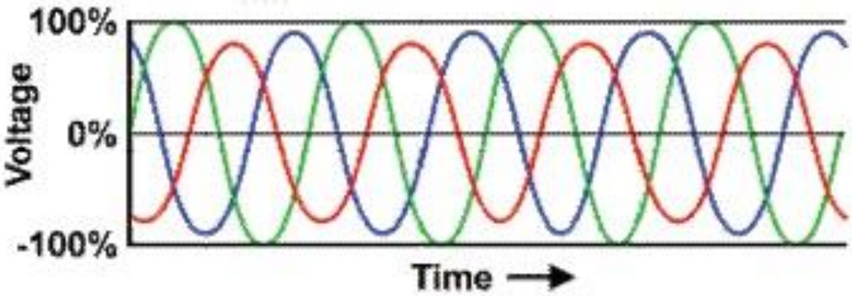

Figure: 11 – Voltage Unbalance[9]

Description: A voltage variation in a three-phase system in which the three voltage magnitudes or the phase-angle differences between them are not equal.

Causes: Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).

Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all three-phase loads. The most affected loads are three-phase induction machines.

The term ‘power quality’ related to the stability of voltage and frequency and the elimination of different types of electrical noise, like harmonic distortion and flicker, present in the system. The system may be grid connected or not, but it’s necessary to find out the source of disturbance which affect the power quality of the plant. Voltage and current must be kept stable because voltage and current distortion creates harmonics in the system.

Here we discuss about the FACTS devices which are very efficient and reliable in power system network to mitigate the issues related with the power quality of the system. The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. Flexible Alternating Current Transmission System (FACTS) is static equipment used for the AC transmission of electrical energy. It is meant to enhance controllability and increase power transfer capability. It is generally power electronics based device. Voltage instability is one of the phenomena which have result in a major blackout. Moreover, with the fast development of restructuring, the problem of voltage stability has become a major concern in deregulated power systems. To maintain security of such systems, it is desirable to plan suitable measures to improve power system security and increase voltage stability margins. FACTS devices can regulate the active and reactive power control as well as adaptive to voltage-magnitude control simultaneously because of their flexibility and fast control characteristics. Placement of these devices in suitable location can lead to control in line flow and maintain bus voltages in desired level and so improve voltage stability margins.

II. BENEFITS OF UTILIZING FACTS DEVICES

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows:

- Better utilization of existing transmission system assets.
- Increased transmission system reliability and availability.
- Maintain the reactive power flow in all over the system network.

- Increased dynamic and transient grid stability.
- Better power quality of supply for sensitive industries.
- Environmental benefits.

The technical benefits of the principal for dynamic applications of FACTS in addressing problems in transient stability, dampening, post contingency voltage control and voltage stability. The devices used for these purposes may be classified as follows:

• Static Synchronous Compensator (STATCOM) -Controls voltage
• Static VAR Compensator (SVC) -Controls voltage
• Unified Power Flow Controller (UPFC)
• Convertible Series Compensator (CSC)
• Inter-phase Power Flow Controller (IPFC)
• Static Synchronous Series Controller (SSSC)

Each of the above mentioned controllers have impact on voltage, impedance, and/or angle (and power)

• Thyristor Controlled Series Compensator (TCSC)-Controls impedance
• Thyristor Controlled Phase Shifting Transformer (TCPST)-Controls angle
• Super Conducting Magnetic Energy Storage (SMES)-Controls voltage and power

From all of these different types of FACTS devices here we discuss only STATCOM, SVC and UPFC. STATCOM and SVC are voltage control devices but UPFC is voltage, impedance and angle (power) control device. These devices have all the ability to mitigate the system problem and system can operate efficiently.

III. FACTS DEVICES DISCUSSION

The FACTS devices are classified as two independent classifications in which the devices of a group of the first classification that can belong to various groups of the second classification. The main difference between first and second generation devices is the capacity to generate reactive power and to interchange active power. The first generation FACTS devices work like passive elements using impedance or tap changer transformers controlled by thyristors. The second generation FACTS devices work like angle and module controlled voltage sources and without inertia, based in converters, employing electronic tension sources (three-phase inverters, auto-switched voltage sources, synchronous voltage sources, voltage source control) fast proportioned and controllable and static synchronous voltage and current sources. These devices not only have the capability in controlling active and reactive power flow in an electrical network but also can redistribute power flow even under highly loaded condition that ultimately have the effect in reducing overall congestion.

I. Static VAR compensator(SVC)

A static VAR compensator (or SVC) is an electrical device for providing fast-acting reactive power on high-voltage electricity transmission networks. SVCs are part of the Flexible AC transmission system device family, regulating voltage and stabilizing the system. The term "static" refers to the fact that the SVC has no moving parts (other than circuit breakers and disconnects, which do not move under normal SVC operation). Prior to the invention of the SVC, power factor compensation was the preserve of large rotating machines such as synchronous condensers. The SVC is an automated impedance matching device, designed to bring the system closer to unity power factor. If the power system's reactive load is capacitive (leading), the SVC will use reactors (usually in the form of Thyristor-Controlled Reactors) to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. They also may be placed near high and rapidly varying loads, such as arc furnaces, where they can smooth flicker voltage. It is known that the SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system. It is observed that SVC controls can significantly influence nonlinear system behavior especially under high-stress operating conditions and increased SVC gains.

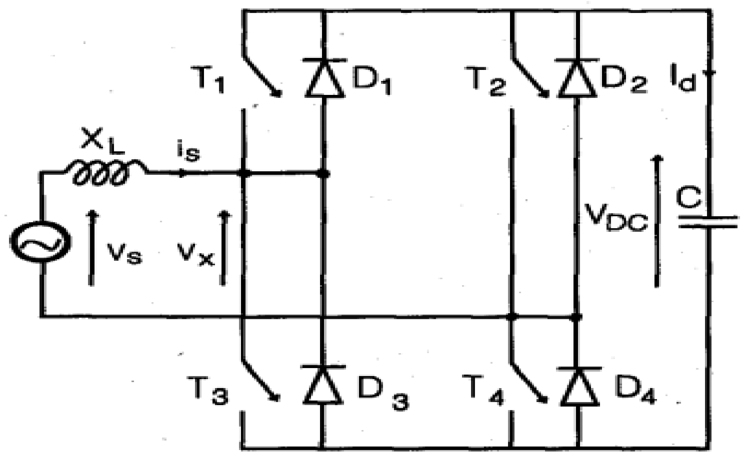

Figure: 12 – Circuit diagram of single phase SVC

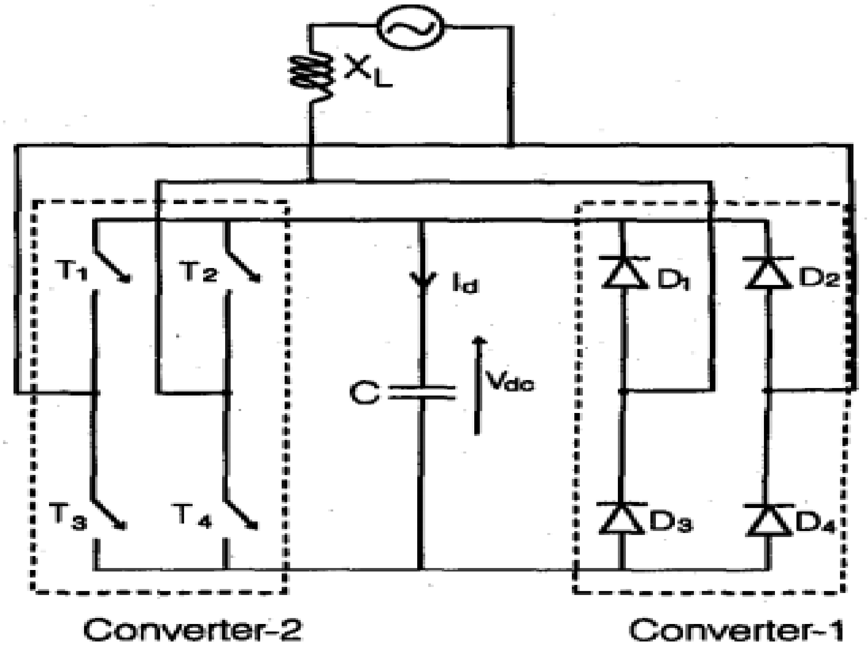

Figure: 13 – Two converter representation of SVC

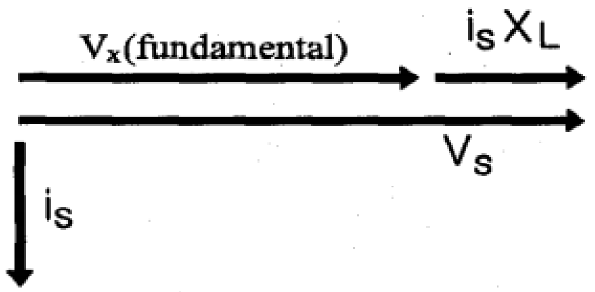

Figure: 14 – Phasor diagram for the lagging operation

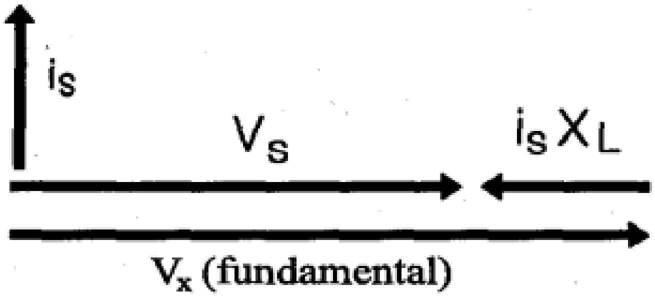

Figure: 15 – Phasor diagram for the leading operation

The single phase SVC circuit shown in Figure - 12 is inherent converters connected in inverse parallel and can be redrawn as Figure - 13. In that circuit, converter-1 acts as an uncontrolled rectifier and a small quantity of average real power flows from the ac side to the dc side through it. Converter–2 operates in the inverter mode, where the real power is in the reverse direction. Initially, when converter - 2 is not conducting, capacitor C is charged up to the peak value of the supply voltage through converter-1 and remains at that voltage as long as no real power transfer occurs between the circuit and the supply. If the switches of converter-2 are operated to obtain the fundamental of the SVC output voltage slightly leading the ac system voltage, converter-2 conducts for a longer period than converter-1 causing a net real power flow from the dc side to the ac side. This in turn decreases the capacitor voltage and thus reactive power is absorbed by the SVC. The converse is true when the SVC output voltage lags the system voltage by a few degrees, to give an increase in the capacitor voltage and hence the leading mode of operation. It may be concluded that the reactive power absorbed or generated by the SVC can be controlled by one parameter, i.e. the phase angle between the fundamental of the SVC output (V) and the ac system voltage. In practice, the internal losses of the SVC must be supplied from the ac system. This can be achieved by operating converter-2 so as to obtain a continuous small flow of real power towards the SVC.

II. Static synchronous compensator(STATCOM)[8]

<u>(i)-Basic principle of operation</u>

In the case of two AC sources, which have the same frequency and are connected through a series reactance, the power flows will be:

a) Active or Real Power flows from the leading source to the lagging source.

b) Reactive Power flows from the higher to the lower voltage magnitude source.

Consequently, the phase angle difference between the sources decides the active power flow, while the voltage magnitude difference between the sources determines the reactive power flow. Based on this principle, a STATCOM can be used to regulate the reactive power flow by changing the output voltage of the voltage-source converter with respect to the system voltage.

(ii)-Modes of operations

The STATCOM can be operated in two different modes:

1- Voltage regulator

The static synchronous compensator regulates voltage at its connection point by controlling the amount of reactive power that is absorbed from or injected into the power system through a voltage-source converter.

In steady-state operation, the voltage V_2 generated by the VSC through the DC capacitor is in phase with the system voltage V_1 (δ=0), so that only reactive power (Q) is flowing (P=0).

i). When system voltage is high, the STATCOM will absorb reactive power (inductive behavior)

ii). When system voltage is low, the STATCOM will generate and inject reactive power into the system (capacitive).

The amount of reactive power flow is given by the equation:

$Q = [V_1(V_1-V_2)] / X$

2- VAR control

In this mode, the STATCOM reactive power output is kept constant independent of other system parameter.

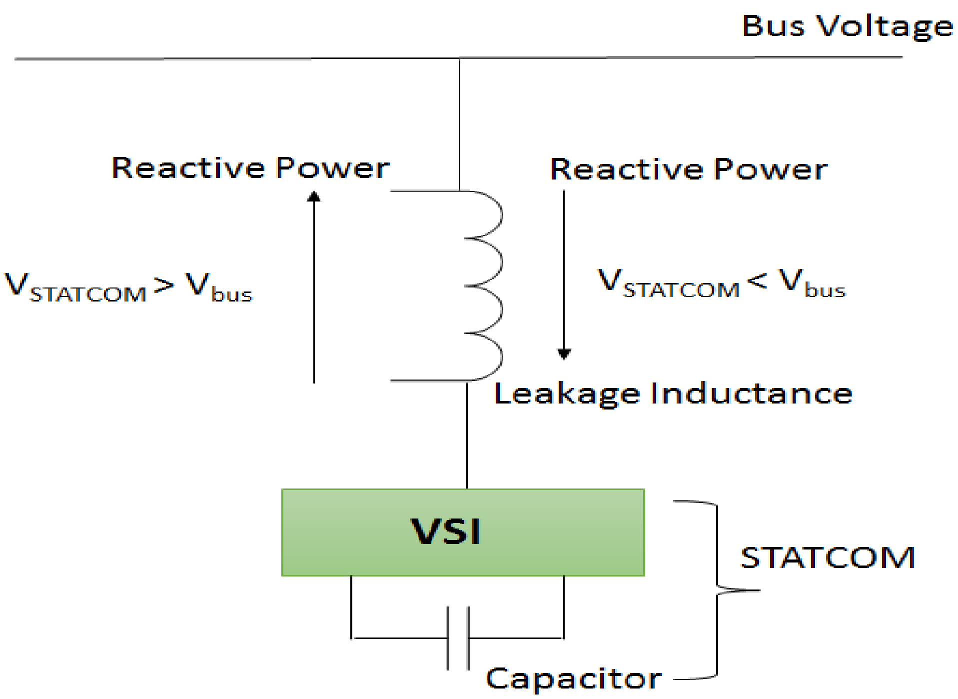

Figure: 16 – Working of STATCOM.[9]

III. STATCOM versus SVC[7]

The STATCOM has the ability to provide more capacitive reactive power during faults, or when the system voltage drops abnormally, compared to ordinary static var compensator. This is because the maximum capacitive reactive power generated by a STATCOM decreases linearly with system voltage, while that of the SVC is proportional to the square of the voltage. Also, the STATCOM has a faster response as it has no time delay associated with thyristor firing. Nevertheless, these advantages come at a higher price (about 20% more).

IV. Unified Power Flow Controllers (UPFC)

UPFC consist of two back to back converters named VSC-1 and VSC-2, are operated from a DC link provided by a dc storage capacitor. These arrangements operate as an ideal ac to ac converter in which the real power can freely flow either in direction between the ac terminals of the two converts and each converter can independently generate or absorb reactive power as its own ac output terminal.

A unified power flow controller (UPFC) is the most reliable device in the FACTS concept. It has the ability to adjust the three control parameters, i.e, the bus voltage, transmission line reactance, and phase angle between two buses, either simultaneously or independently. A UPFC performs this through the control of the in-phase voltage, quadrature voltage and shunt compensation. The UPFC is the most versatile and complex power electronic equipment that has emerged for the control and optimization of power flow in electrical power transmission systems. It offers major potential advantages for the static and dynamic operation of transmission lines. The UPFC was devised for the real-time control and dynamic compensation of ac transmission systems, providing multifunctional flexibility required to solve many of the problems facing the power industry. Within the framework of traditional power transmission concepts, the UPFC is able to control, simultaneously or selectively, all the parameters affecting power flow in the transmission line. Alternatively, it can independently control both the real and reactive power flow in the line unlike all other controllers.

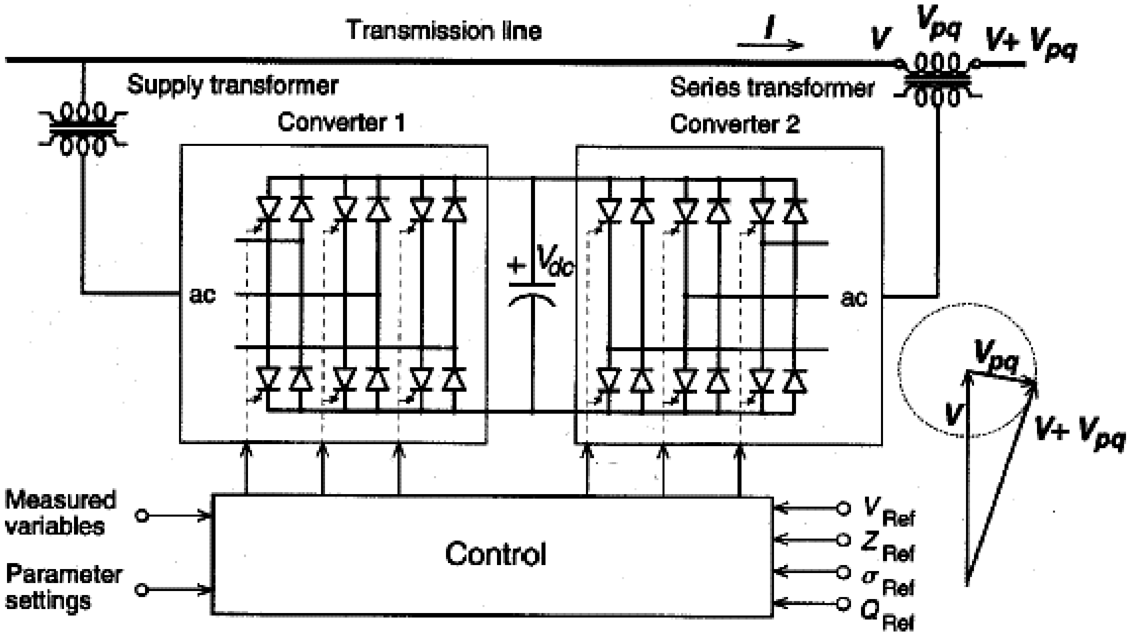

Figure: 17 – Unified Power Flow Controllers (UPFC).[9]

V. COMPARISON BETWEEN SVC, STATCOM AND UPFC

The comparison between SVC, STATCOM and UPFC is given in the following table:

Table 1: Comparison between SVC, STATCOM and UPFC.

Device capabilities	SVC	STATCOM	UPFC
Type of device	Shunt	Shunt	Series and shunt
Main function	Voltage control	Voltage control	Voltage and power flow control
Controllers	Thyristor	IGBT, GTO	GTO
Cost	Low	Medium	High
Reliability	Low	Medium	High
Transmission capacity	Low	Low	High
Voltage stability	High	High	High

From the above comparison as we can see STATCOM is the most suitable FACTS controller from the system optimization and controlling point of view. There are some limitations but we can manage it according to the using system.

VI. RESEARCH GAP FROM REFERENCES

The majority of power quality issues experienced by customers can be attributed to sags, harmonics, and transients. However, several other power quality conditions can also disrupt processes and equipments, such as swells, under voltages, over voltages, interruptions, DC offsets, notching, noise, voltage fluctuations, and frequency variations. Solutions exist for all of these types of conditions, but the biggest step that needs to be taken to reduce the capital and operational expenditures that are a direct result of power quality is to have the capability to measure, detect, and visualize the power quality events and conditions.

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