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Resolution of Power Quality Issues

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***Abstract*—**Mainly the power quality problems are - active power, reactive power, variation in voltage, flicker and harmonic contents. Electric power quality relates to non-standard voltage, current or frequency that results in failure of consumer end equipment or malfunctioning of equipments. The power quality can affect the performance of the electrical equipments; the electrical equipments may have to be derated for the poor power quality. Further, sensitive loads like PLCs, adjustable speed drives may trip leading to financial and time losses to the industry. This paper gives the power quality issues, their effects and consequences on the electrical equipments and the methods to reduce them.

***Keywords*-Electric Power Quality, Power Quality Effects, Mitigation, Flexible AC Transmission System devices.**

I. INTRODUCTION

Power Quality is defined as power that enables the equipment to work properly. A power quality problem can be defined as any deviation of magnitude, frequency, or purity from the ideal sinusoidal voltage waveform. Good power quality is benefit to the operation of electrical equipment, but poor power quality will produce great harm to the power system [2]. Harmonics are defined as sinusoidal waveform having a frequency equal to an integer multiple of the power system fundamental frequency. It is a component of a periodic waveform. If the fundamental frequency multiple is not an integer, then we are dealing with interharmonics [2].

What do we mean by 'power quality'? A perfect power supply would be one that is always available within voltage and frequency tolerances, and has a pure noise free sinusoidal wave shape. The Power Quality area is very broad and it has many branches that deal with different problems and issues. Any device to be connected to the electric grid has to fulfil standardized power quality requirements. This is to ensure that the electric grid is protected from unacceptable disturbances. The connected device, therefore, is connected to the grid with electric quantities within guaranteed limits [1].

Modern electronic equipments and devices, such as microprocessors, microcontrollers, tele-communications equipment and sensitive computerized equipments etc. are generally responsible to PQ problems. A poor PQ has become a more important issue for both power suppliers and customers. Poor power quality means there is a deviation in the power supply to cause equipment misoperation or may failure.

Table I shows power quality defects, which are fall into five categories and their main possible causes [1].

TABLE I. POWER QUALITY DEFECTS AND THEIR MAIN POSSIBLE CAUSE

Type	**Power Quality Defects**	**Main Possible Causes**
1	Harmonic distortion	Arising within the customer's own installation and may or may not propagate onto the network
2	Blackouts	Caused by the supplier but can also by the failure of on-site equipment, conductors and connections.
3	Under or over voltage	Caused by fluctuation of the supply voltage, typically due to the use of large fluctuating loads (flicker).
4	Dips (or sags) and surges	The responsibility of the supplier due to harmonic current.
5	Transients	Switching or lightning strikes on the network and switching of reactive loads on the consumer's site or on the same circuit.

II. POWER QUALITY ISSUES & ITS CONSEQUENCES

Perfect power quality means that the voltage is continuous and sinusoidal having constant figures of amplitude and frequency. Power quality can be expressed in terms of physical characteristics and properties of electricity. It is most often described in terms of voltage, frequency and interruptions [3].

A. *Voltage Swell*

This is a short term increase in voltage for a few cycles duration.voltage swell is an increase in RMS voltage as shown in fig.1 in range of 1.1p.u to 1.8p.u for duration greater than half cycle and less than 1 minute.

Swells are usually associated with system fault conditions, but they are much less common than voltage sags. A swell can occur due to a single line-to-ground fault on the system which can result temporary voltage rise on the otherunfaulted phases. Swells can also be caused by switching off a large load or switching on a large capacitor bank. Voltage swells can put stress on computer and many home appliances. It also causes tripping of protective circuit of an adjustable speed drive [4].

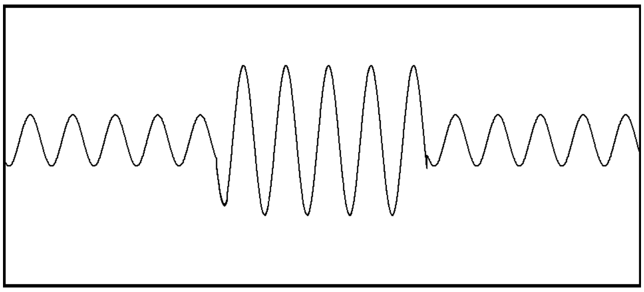

Fig. 1. Voltage Swell

B. *Voltage Sag*

This is a short-term drop in voltage as shown in fig 2 in the range of 0.1p.u to 0.9p.u, for duration greater than half cycle and less than 1 minute. It is defined as decrease in voltage level between 10 to 90% of the nominalrms voltage at the rated power frequency i.e. 50Hz [4].

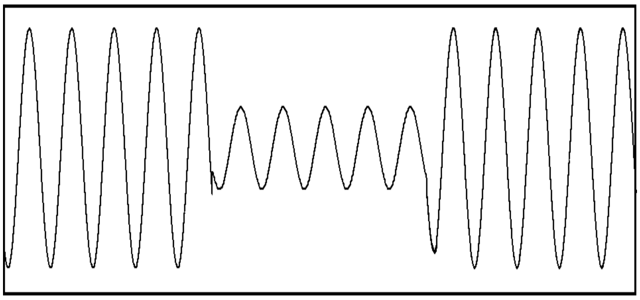

Fig. 2. Voltage Sag/Dip

Voltage sags are related to with system faults but it also caused by switching of heavy loads like transformer, circuit breaker or starting of large motors. Voltage sag can cause loss of production in automated process since a voltage sag trip a motor or cause its controller to malfunction, namely microprocessor based control system, programmable logic controller, adjustable speed drives, that may lead to a process stoppage, tripping of contractors and loss of efficiency of electric machine.Impact of long duration variation is greater than those of short duration variation [5].

C. *Short Interruption*

Short interruption causes tripping of protection device, stoppage of sensitive equipments like personal computer, programmable logic controller[5].

It is total interruption of electric supply for duration from few milliseconds to 1 or 2 sec. It causes due to mainly opening and automatic closing of protective devices.

D. *Long Interruption*

It is total interruption of electric supply for duration of 1-2 seconds. It causes due to equipment failure in power system and failure of protection equipments [5].

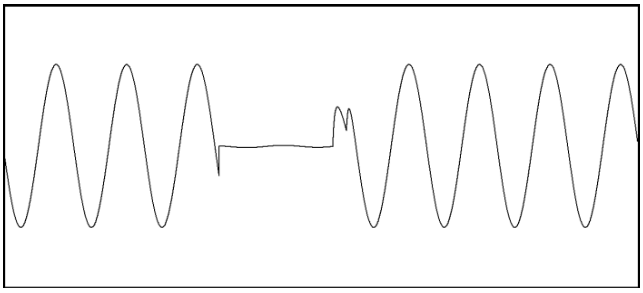

Fig. 3. Interruption

Interruptions can results the power system faults, equipment failure, and control system malfunction. The interruptions are always less than 10% of nominal supply voltage. The duration of an interruption due to equipment malfunctions or loose connections can be irregular. Ninety percent of fault on overhead distribution lines are of temporary nature. Basically, these faults are due to lightning or tree limbs or animals causing grounded.

A temporary interruption lasting a few seconds can cause a loss of production, erasing of computer data etc. The cost of such an interruption during peak hours can be very heavy [4].

E. *Voltage Flicker*

Flicker is defined as the "Impression of fluctuating brightness or colour, occurring when the frequency of observed variation lies between a few Hertz and the fusion frequency of images". Flicker comes due to rapid on-off of incandescent and fluorescent lamps. It results rapid variation in voltage due to fast changes in load as shown in fig. 4.

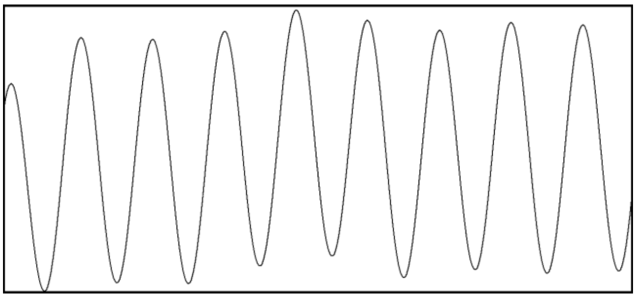

Fig. 4. Voltage Flicker

Flicker can occur due to electric arc furnaces, wielding machines, large ASD with inadequate DC-link filtering system. Voltage flickers are caused by arc discharge lamps, arc furnaces, starting of large motor, arc welding machines etc. Flicker has adverse effects on human health due to the high frequency flickering of light bulbs, fluorescent tubes or television screen can cause stress on the eyes resulting in headache. The flicker can also reduce the life of electronic equipments like lamps, television, radioetc [4].

F. Voltage Unbalance

Voltage imbalance fig.5 is deviation in the magnitude and phase of one or more of the phases, of a three phase supply, with respect to the magnitude of the other phase and the normal phase angle (120deg). Voltage imbalance (or unbalance) is defined as the ratio of the negative or zero sequence components to the positive sequence component. The negative or zero sequence voltages in a power system generally results from unbalanced loads causing negative or zero sequence currents to flow in the system. Voltage imbalance can cause temperature rise in motors and can even cause a large motor to trip [4].

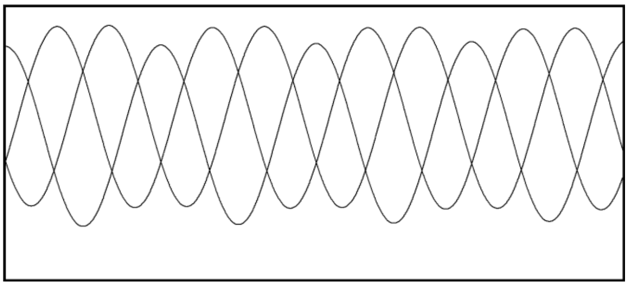

Fig. 5. Voltage Unbalance

G. Harmonics

It is a sinusoidal component of a periodic wave having a frequency that is an integral multiple of the fundamental frequency as shown in fig.6. Harmonics can be considered as voltages or current present on an electrical system at some multiple of the fundamental frequency.

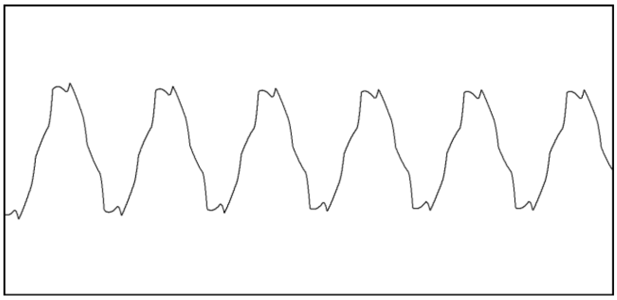

Fig. 6. Voltage Harmonics

Non-linear elements in power systems such as power electronic devices, static power converters, arc discharge devices, and lesser degree rotating machines create current distortion. Static Power converters of electrical power are largest nonlinear loads and are used in industry for a variety of purposes, such as electrochemical power supplies, adjustable speed drives, and uninterruptible power supplies. These devices are useful because convert ac to dc, dc to dc, dc to ac, and ac to ac. Harmonics cause wave from distortion power system problems such as communication interference, heating, and solid-state device malfunction can be direct result of harmonics [5].The THD limit for various level of system voltages are given in the table II.

TABLE II. VOLTAGE HARMONICS LIMITS

System Voltage (KV)	**Total harmonic Distortion (%)**
400	2.0
220	2.5
132	3.0

The voltage variation, sag, swell, harmonicscauses malfunctioning of electronics equipments namely microprocessor based system, programmable logic controller, adjustable speed drives etc. Due to all this problems it may cause tripping of contractors, protection devices, also stoppageof sensitive equipments like computer, programmable logic control system and may be damage the sensitive equipments. Due to all this problems the whole system will be derated.

III. POWER QUALITY MITIGATION TECHNIQUES

The different technologies are available for power quality mitigation based on the system requirement are given below:

(1) Reactive power compensation technologies:
(a) Active Filters
(b) Dynamic voltage restores (DVR)
(c) Static VAR compensator (SVC)
(d) Static synchronous compensator (STATCOM)
(e) Static synchronous series compensator (SSSC)
(f) Synchronous condenser
(g) Unified power flow controller (UPFC)

(h) Interline power flow controller (IPFC)
(2) Constant Voltage transformer
(3) Magnetic Synthesizers
(4) On line UPS
(5) Flywheel Energy storage system

As discussed the poor power quality affects the system parameters and also end user equipments. So to compensate reactive power and to improve power quality FACTS devices are introduced. Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. Flexible AC Transmission Systems, called FACTS, is very popular which can improve system performance by means of power electronic devices. FACTS devices inject a current into the system to correct the voltage sag and swell. Several FACTS-devices have been already introduced for various applications in worldwide [6]. The basic applications of FACTS-devices are: Power flow control, Increase of transmission capability, Voltage control, Reactive power compensation, Stability improvement, Power quality improvement, Power conditioning, Flicker mitigation [6]. The introduction of FACTS-devices is achieved through switched or controlled shunt compensation, series compensation or phase shift control. The devices are used for current, voltage or impedance controllers. As stated above different techniques for power quality improvement out of this some reactive power compensation techniques are explained in details.

A. Active Filters

A flexible and popular solution for power quality related problems is active power filters. Mainly the active filters are connected to low and medium voltage system either in series or in shunt. Series active filter must operate in co-ordination with shunt passive filters to reduce and compensate load side current harmonics. Shunt active filters are operating as a current source and series active filters are operates as a voltage source [7].

*1) Series Active Filter:*Series active power filter compensate current distortion which are developed by non-linear load by providing a high impedance path to the harmonic currents which allows to flow the high frequency current through the LC passive filter connected in parallel to the load as shown in fig.7.

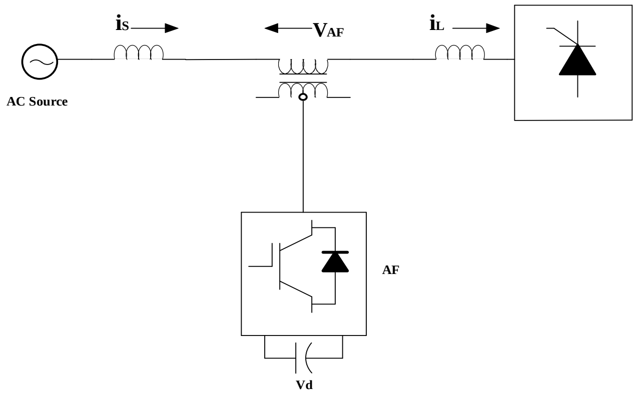

Fig. 7. Series Active Filter

The high impedance imposed by the series active power filter is created by generating a voltage of the same frequencythat the current harmonic component that needs to be eliminated. Voltage unbalance is corrected by compensating the fundamental frequency negative and zero sequence voltage components of the system [7].

2) Shunt Active Filter: Shunt active filters compensate the load side current harmonics by injecting equal-but- opposite harmonic compensating current in the system.

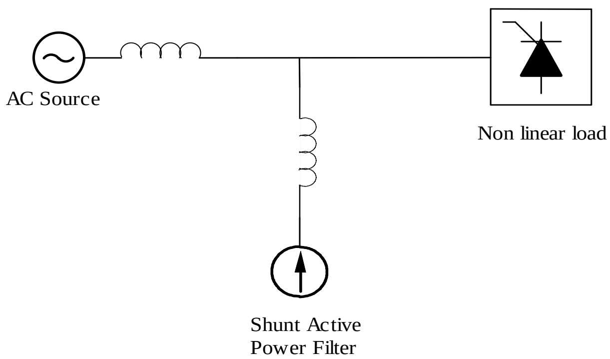

Fig. 8. Shunt Active Filter

In this system the shunt active filter operates as a current sourcethat is phase shifted by 180^o and it can inject the harmonic components developed by the load. The current compensation block diagram of the shunt active filter is shown in Fig.8 [7].

This concept is applicable to any type of load which consist a harmonic source.We can also compensate the load power factor by using active shunt filters. Shunt active power filters are normally implemented with pulse-width modulated voltage source inverters.

B. Dynamic Voltage Restorer

During voltage dip shunt connected VSC boost the voltage at that point by injecting current in the point of connection. Also by injecting voltage into the grid with series connected VSC we can mitigate the voltage dips. The injected voltage adds the supply voltage during the voltage dip, and restores the load voltage to its normal value. Both in shunt and series configuration, the VSC must be controlled properly to inject the necessary current or voltage into the grid to compensate voltage dip.

The block diagram of DVR is shown in fig.9. it represents the Thevenin equivalent circuit. The impedance Zth depends on the fault level of the load side bus [3]. The main functions of DVR are reactive power compensation, voltage regulation, compensation of voltage sag and swell and unbalance voltage compensation for three phase system.The VSC generates a three phase ac output voltage which is controllable in phase andmagnitude. These voltages are injected into the ac distribution system in order to maintain theload voltage at the desired voltage reference.

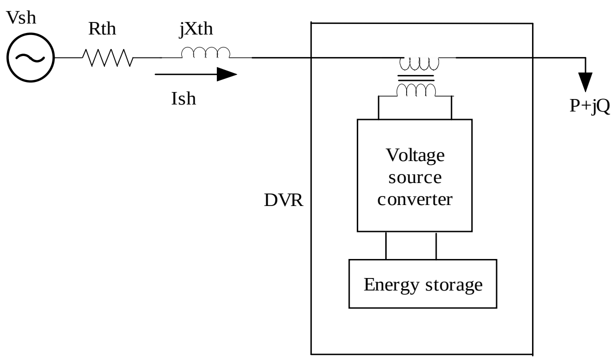

Fig. 9. Block Diagram of DVR

C. Static VAR Compensator

Electrical loads both generate and absorb reactive power. Since the transmitted load varies considerably from one hour to another, thereby the reactive power balance in a grid varies. The result can be unacceptable voltage variations or even a voltage depression and at the extreme a voltage collapse. A rapidly operating Static Var Compensator (SVC) can continuously provide the reactive power required to control dynamic voltage oscillations under various system conditions and thereby improve the power system transmission and distribution stability.

With installing an SVC at one or more suitable points in the network which can increase transfer capability of system and also reduce losses meanwhile maintaining a smooth voltage profile under different network conditions. In addition, an SVC can mitigate active power oscillations through voltage amplitude modulation[9].In industrial applications, SVCs are placed where rapidly varying loads and at high load sides such as arc furnaces, where they can smooth flicker voltage.The main advantage of SVCs over

simple mechanically-switched compensation schemes is their near-instantaneous response to changes in the system voltage [9].

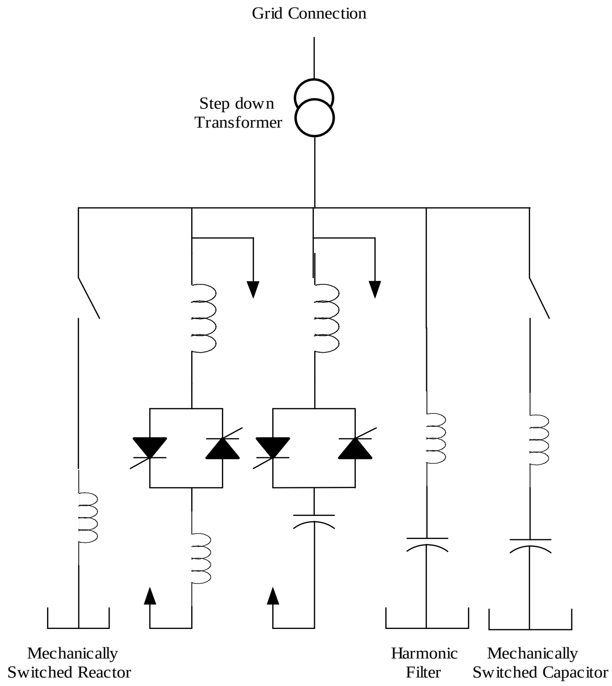

Fig. 10. Block Diagram of SVC

D. STATCOM

In 1999 the first SVC with Voltage Source Converter called STATCOM (STATicCOMpensator) went into operation [11]. STATCOMs are based on Voltage Sourced Converter (VSC) topology and utilize either GTO or IGBT devices. STATCOM is one of the custom power devices, used for supplying reactive, harmonic currents of load demand. It is a device connected in derivation, basically composed of a coupling transformer, that serves of link between the electrical power system (EPS) and the voltage synchronous controller (VSC), that generates the voltage wave comparing it to the one of the electric system to realize the exchange of reactive power. The STATCOM is like an electronic synchronous condenser.For three phase STATCOM the reactive power in each phase is supplied by circulating the real power between the other phases.

A STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C capacitor which provides the D.C voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the d.c. side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the a.c supply. The link inductor links this voltage to the a.c supply side. This is the basic principle of operation of STATCOM [7]. Such configuration allows the device to absorb or generate controllable active and reactive power.

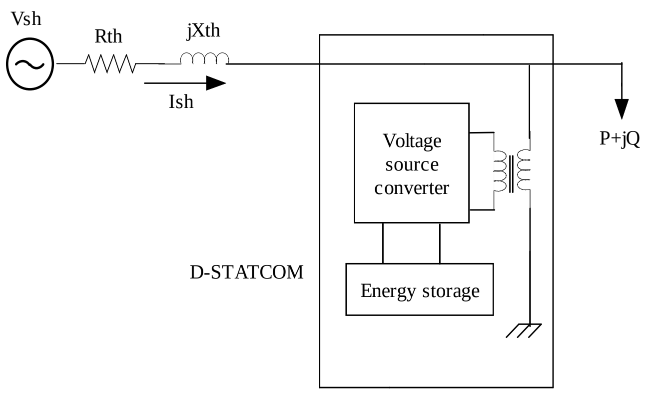

Fig. 11. Block Diagram of STATCOM

1) Advantages of STATCOM over SVC, DVR: There are so many advantages of STATCOM over SVC and DVR and other FACTS devices.

- The STATCOM provides better damping characteristics than the SVC and DVR as it is able to exchange active power with the system.
- The reactive power provided by STATCOM is independent of the actual voltage on the connection point of STATCOM.
- STATCOM have almost the same impact on the system behavior as long as they operate within their control ranges.
- The STATCOM is more robust and effective than an SVC in providing voltage support and stability improvements.
- A modular design of the STATCOM allows for high availability i.e. without the loss of the entire compensation system we can change faulty module of the STATCOM.

A STATCOM can improve power-system performance in such areas as the following:

- The transient stability;
- The voltage flicker control; and
- It also controls real power in line when it is needed
- The dynamic voltage control in Transmission and distribution systems;
- The power-oscillation damping in power transmission systems;

2) Application of STATCOM: STATCOM has the following applications in power system.

- Improvement of steady-state power transfer capacity
- Reduction of temporary over-voltages developed in power system.
- To damp the oscillations developed in power system
- Load balancing of individual phases.
- Reactive compensation of AC-DC converters and HVDC links.
- Effective voltages regulation and control.
- Reduction of rapid voltages fluctuations (flicker control) [10].

IV. CONCLUSION

From the various mitigation techniques discussed above we conclude that STATCOM is one of the promising FACTS device which improves the quality of power, because STATCOM has the potential to maintain quadrature relationship with line current to correct the voltage sag by injecting active power to grid and it provides linearly decreasing compensating reactive power with decreasing system voltage. Statcom also maintains the source voltage and current in-phase and support the reactive power demand for power system. And hence this enhances utilization factor of transmission line. This paper presents various power quality issues and its consequences on the consumer, electric utilityalong with various mitigation techniques to improve the power quality.

V. FUTURE SCOPE

Demand for power is always increasing day by day. The power quality problems are also following the same trend and increasing day by day. So there is need to reduce such power quality problems and make the supply system efficient. FACT devices can be controlled through different techniques to get better coordination between real and reactive power.

STATCOM is one of the promising technologies to overcome the power quality problems. The power quality can be still improved by using soft computing techniques like Unified power flow controller.

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