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POWER QUALITY MITIGATING DEVICES: REVIEW

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Abstract

Modern-day power systems are facing severe Power Quality problems such as high reactive power burden, harmonics, voltage sag, swell, notches, flickers, etc. In recent years, the quality of power delivered to consumers is a major concern for the energy engineers and so there is more emphasis on this area. This paper throws some light on the classification of power quality problems and various types of techniques used for their mitigation. With the advancement in technology, different types of devices are introduced to mitigate the power quality problems. In this paper, the devices used for mitigation of power quality problems are categorized into three generations, and carried out a brief discussion about all of them.

Keywords: PQ; DVR; STATCOM; UPFC; UPQC.

I. INTRODUCTION

Electrical Energy is the basic necessity for the overall development of any country. With the advancement in the area of science and technology, the dependency on electrical energy has increased rapidly. Therefore, the energy demand also increased by many times. Generation and supply are the two most common parameters of good electrical energy. [1] Equates the term power quality with voltage quality. Worldwide complaints due to power quality disturbances are increasing among different types of consumers. Poor power quality might cause premature failure of instruments and other major technical problems which lead to huge financial loss.

In a practical power system, ideal voltage supply does not exist. The reason behind this is the nonlinear characteristics of commercial and industrial loads. The AC power systems are designed to operate at a sinusoidal voltage of a given frequency and magnitude. Any significant deviation in the waveform magnitude, frequency, or purity is a potential power quality problem. The power quality problem may be transients, overvoltage, under voltage, sag, swell, notch or harmonics, etc. Power quality is ultimately a consumer-driven issue, and the end user's point of reference takes precedence. Therefore, a power quality problem is described as, "any change in voltage, current or frequency that interferes with the normal operation of electrical equipment."

II. CLASSIFICATION OF POWER QUALITY PROBLEMS

Power quality disturbances are classified in different categories by various researchers and reviewers [3][4][7]. Some of them classified them in terms of events occurring at different levels i.e. transmission, distribution and end use devices etc. And some researchers emphasized on intensity of the disturbances and categorized the problems on that basis. Here the power quality disturbances are broadly classified on the basis of duration and magnitude.

Table.1: Various Types of Power Quality Disturbances

Power Quality Disturbances		Causes	Impacts
1. Transients (from few ns to 50ms)	**(i) Impulsive transients:** Sudden increase in steady-state current/voltage levels.	Lightning, capacitor bank switching.	Insulation failure, loss of data, damage of various end-user devices.

	(ii) Oscillatory transients: It is a sudden, non-power frequency change in steady-state condition of voltage, current, or both, that includes both positive and negative polarity values.	Switching operation of inductive or capacitive load, transformer energization, poor grounding, and utility fault clearing.	Loss of data, tripping of adjustable speed drive(ASD), and other control devices.
2. Short duration disturbances (0.5 cycles to 1 minute)	**(i) Interruption:** As per IEEE std 1159-1996, An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time less than a minute.	Power System faults, equipment failures, control malfunctions.	Malfunction of devices, loss of data, tripping of various devices.
	(ii) Voltage Sag: A decrease in RMS voltage or current at the power frequency to between 0.1 pu and 0.9 pu for duration from 0.5 cycles to 1 minute (As per IEEE std 1159-1995).	Faults on distribution and transmission networks, connection of heavy loads, faults in consumer's appliances, and start-up of large motors.	Malfunction of microprocessor-based control systems (PCs, PLCs, ASDs, etc), tripping of contactors, and electromechanical relays.
	(iii) Voltage Swell: As per IEEE std 1159-1995 swell is defined as, an increase in RMS voltage or current between 1.1 pu to 1.8 pu at the power frequency for durations from 0.5 cycles to 1 minute.	Start/stop of heavy loads, badly dimensioned power sources, poorly regulated transformers (mainly during off-peak hours).	Data loss, flickering and lighting of screens, stoppage or damage of sensitive equipment, insulation degradation.
3. Long Duration Disturbances (more than 1 minute)	**(i) Sustained interruption:** When the supply voltage becomes zero or falls below 0.1 pu for a period of time in excess of 1 minute.	Equipment failure in power system networks, storms, objects striking poles, human error.	Stoppage of all equipments.
	(ii) Under voltages: A decrease in RMS ac voltage to less than 0.9 pu for more than 1 minute time duration.	Undersized or overloaded transformers, overloading, undersized wiring which causes significant I-R drops.	Flickering of lighting and screens, increment in losses in constant power and constant torque motors.
	(iii) Overvoltage: An overvoltage is an increase in the RMS ac voltage greater than 1.1 pu for a duration longer than 1 minute.	Internal causes (like switching surges, insulation failure, arcing ground, resonance) and External causes (direct lightning stroke and other atmospheric disturbances).	Line insulators flashover or puncture, Voltage oscillation in sub-circuit, damage of sensitive equipment.
	(iv) Voltage unbalance: If voltage magnitude of all phases is not equal or phase angle	Incorrect distribution of single-phase loads on	Reduced efficiency because of excess losses in electromagnetic devices,

	differences deviate from 120 degree.	three phase supply, defective transformers.	reduced torque and speed, dim lighting.
	(v) Voltage fluctuations: It is a systematic variation of the voltage waveform.	Arc furnace, voltage fluctuation in utility transmission and distribution system.	The flickering of lighting and screens, visual irritation in supply power.
	(vi) Frequency variations: The deviation of fundamental frequency from its standard value.	Faults on bulk power transmission system, a large block of load being disconnected.	Speed variation of machines, may create power system stability problems.
4. Waveform distortions	**(i) Harmonics:** Harmonics are integer multiples of the supply frequency at which supply system is designed to operate.	Non-linear loads such as power electronics equipment including ASDs, SMPS, data processing equipment, high efficiency lighting, arc furnaces, welding machines etc.	Conductor overheating, overheating of the windings, decreased motor performance, random data errors, electromagnetic interference with communication system.
	(ii) Notching: It is a periodic voltage disturbance caused by the normal operation of power electronic devices when current is commutated from one phase to other.	When the current commutates from one phase to other.	Destruction of components and insulation materials, data processing errors.
	(iii) Noise: Noise is the unwanted electrical signals with broadband spectral content lower than 200kHz superimposed upon the voltage or currents in the conductors.	Power electronic devices, control circuits, electromagnetic interference.	Disturbs sensitive electronic devices such as microcomputer and programmable computer.
	(iv) DC offset: The presence of a dc voltage or current in an ac power system	As the result of a geomagnetic disturbance, incandescent light bulb life extenders.	Impact on insulation, addition heating of transformer.

III. PQ MITIGATION TECHNIQUES

Over the years, different types of power enhancement devices are developed to protect equipment from power disturbances. These devices play an important role in improving power quality issues from the system. The PQ mitigation devices can be categorized into three generations namely G1, G2, G3 (where G stands for Generation).

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G1	G2	G3
• Passive Power Filters • Active Power Filters • Hybrid Filters • Zig-Zag Transformers	• **Dynamic Voltage Restorer(DVR)** - to mitigate, unbalancing, sag • **SVC, STATCOM** - To mitigate flicker	• UPFC • UPQC • Multifunctional DG

Generation 1 (G1):

1. Passive Power Filters: Number of passive techniques are available to reduce the level of harmonic distortion in an electrical network. Passive filter is basically a combination of inductors, capacitors and resistors designed to eliminate one or more harmonics. The most common combination is simply an inductor in series with a shunt capacitor, which short circuits the major distorting component from the system.

Harmonic mitigation by passive filter is based on bypassing the harmonic current from the harmonic source by creating a low impedance path at specified frequency [5]. Therefore, a well-designed harmonic filter should have the following characteristics [5], [6]:

i-Low impedance: at the tuned frequency in order to trap the harmonic current. ii- High power factor at fundamental frequency: otherwise it may cause over-voltage or under-voltage problems. iii-Low power loss as filter resistor is basically inserted to damp the undesired parallel resonance. However, a large resistor can lead to a high power loss. The following figure shows several types of commonly used passive filter arrangements:

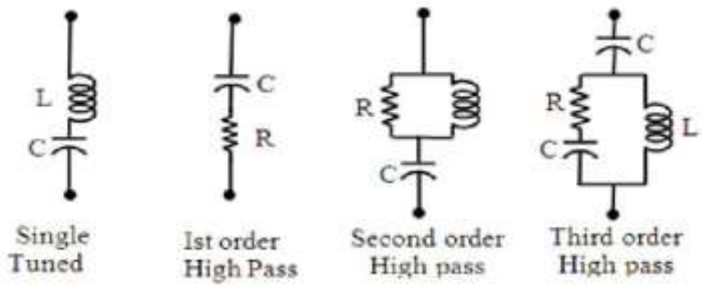

Fig.1 Common passive filter configuration

Passive Filters are traditionally used to absorb harmonic currents because of low cost and simple robust structure. However, they provide fixed compensation and create system resonance [7]. Moreover, they are ineffective if load conditions are variable and it is necessary one circuit to filter each harmonic and there is no isolation between input and output.

2. Active Power Filters: Active power filters are classified broadly into series and shunt configurations. However, a combination of series and shunt is also used for power quality improvement. These filters are more responsible than passive filters, no resonance issue and they also allow isolation between input and output.

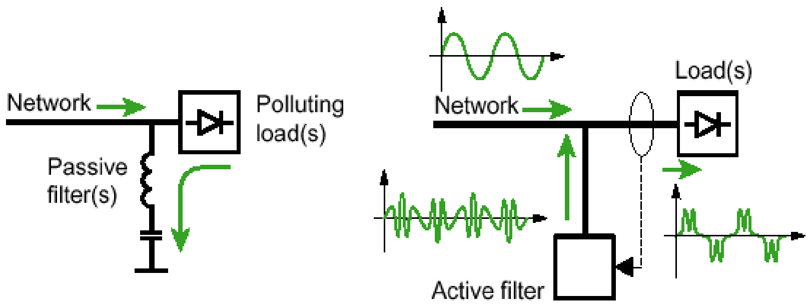

Fig.2: Passive and Active Filters for Harmonic Mitigation

The APF theory is now mature for providing compensation for harmonics, reactive power, and /or neutral current in current in ac networks. One of the major factors in advancing of the Active Filter technology is the advent of fast self-commutating Solid state devices.

But the cost of active filters is always an area of concern and they provide a complex control system. These filters are limited in their frequency ranges. The main drawback of active filters is that their rating is sometimes very close (up to 80%) to the load, and thus it becomes a costly choice for power quality improvement in a number of situations. [8]

3. Hybrid Mitigation Technique:

To reduce the ratings of active power filters, active filters and passive filters were combined together by many researchers [9-12]. With the increasing use of non-linear equipments for industrial as well as residential applications, the power quality is deteriorated very badly. So for improving the power quality active and passive as alone are not sufficient, Thus the concept of Hybrid Filters came into limelight. Hybrid technology is the connection between passive filters and active power filters. Hybrid filter is based on the harmonic reduction and reactive power compensation [5]. There are many theories like pq, d-q theory and RLC algorithm for improvement of power quality. The passive circuit performs basic filtering action at the dominant harmonic frequencies (e.g. 5th or 7th) whereas the active elements, through precise control, mitigate higher harmonics. This will effectively reduce the overall size and cost of active filtering. [14]

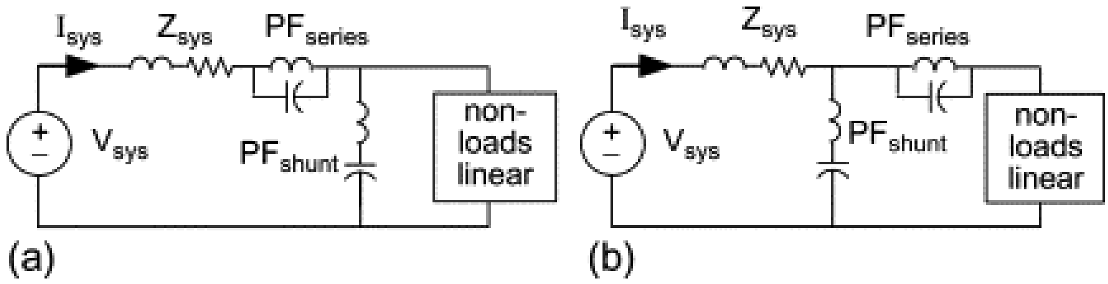

Fig.3: Single-phase hybrid filter (including two passive filters) as a combination of

(a) passive-series and passive-shunt filters, (b) passive-shunt and passive-series filters [14]

Generation 2(G2):

With the advancement of power electronics and Flexible AC Transmission (FACT) devices the PQ mitigation technology becomes more advanced. The following devices come under this generation:

1. Dynamic Voltage Restorer(DVR): Dynamic voltage restorer or in short DVR is a PQ mitigation device used to overcome the problem of voltage unbalancing and Sag. The DVR acts as a voltage source connected in series with the load. The output voltage of the DVR is kept approximately constant voltage at the load terminals by using a step-up transformer and/or stored energy to inject active and reactive power in the output supply trough a voltage converter.

The DVR detects a drop in the line voltage during a cycle and restores the rest of the waveform by using energy in storage elements such as batteries. The DVR consists of DC power sources such as batteries, supercapacitors, flywheels etc. The DVR detects the sag and generates AC power from the DC power source by using converter. The generated power is fed to the line transformer to correct the sag so that the sensitive load receives a highly reliable AC input power [13].

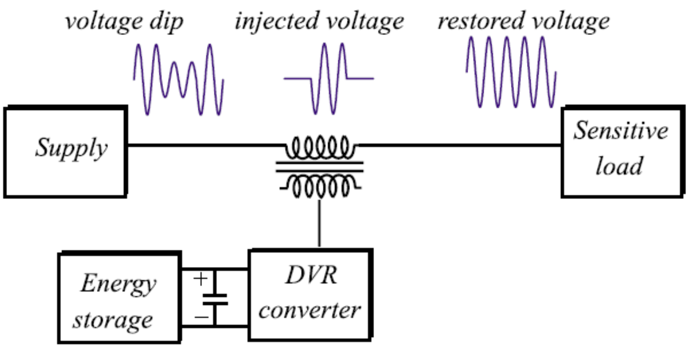

Fig.4: Working principle of Dynamic Voltage Restorer [15]

Simulation results in [15] shows the DVR abilities in harmonic elimination as well as voltage mitigation. It is concluded that DVR successfully mitigated long duration voltage sags/swells and perfectly restored the load voltage almost 1 p.u. study on rated power of injection transformer shows, although larger transformer has a better performance in sags/swells mitigation, it increases THD of load voltage when the supply voltage distorted, so there is a trade-off between rms value and THD of the load voltage.

DVR is less costly and has more energy capacity compared to other devices of same generation.

2. Static Var Compensator(SVC): SVCs can be applied to either utility systems or industrial systems. They consume reactive power and regulate voltage. Static Var compensators are being used to provide voltage control, Var compensation, damping of oscillations, and improved transient stability in power systems[16].

Static Var Compensator is a shunt-linked static VAR producer whose output is regulated to exchange capacitive or inductive current so as to keep in good condition or regulate specific parameters of an electrical power system, typically bus voltage. SVC is founded on thyristors without gate turn-off ability. There are two main types of Static Var Compensators in common usage: Thyristor Controlled Reactor(TCR) and Thyristor Switched Capacitor(TSC). TCR is the most common scheme, it provides a fixed capacitor bank to provide reactive power and a thristor-controlled inductance that is gated on in various amounts to cancel all or part of the capacitance. The capacitors are frequently configured as filters to clean up the harmonic distortion caused by the thyristors.

The advantage of SVC is that it can control voltage rapidly and moreover it can control overvoltage with high speed. Some more advantages like increase the power transmission capability of the transmission lines and also improve the transient stability of the system. But there are some disadvantages as well like it has limited overvoltage capability and comparatively expensive.

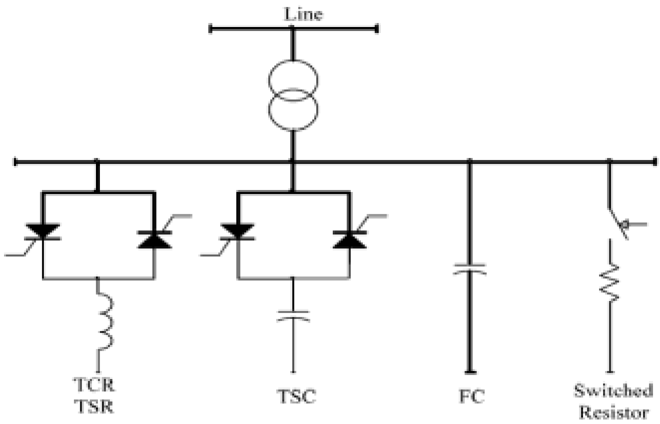

Fig.5: Static Var Compensators [3]

3. Static Synchronous Compensator(STATCOM): STATCOM has the same functional compensation capability as of SVC. However, the basic operating principles of STATCOM, which, with a converter based var generator, functions as shunt connected synchronous voltage source, are fundamentally different from those of SVC. This basic operational difference accounts for the STATCOM's overall superior functional characteristics, better performance and greater application flexibility [17].

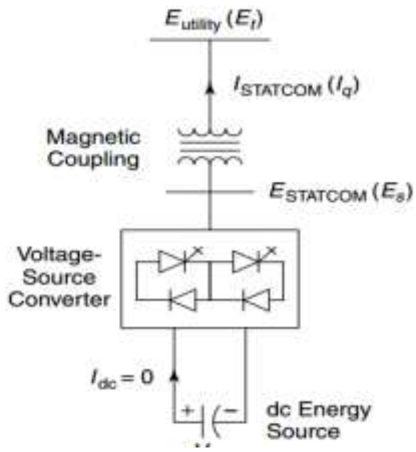

Fig.6: Principle Diagram of STATCOM

STATCOM is usually installed to support electrical networks that have a poor power factor and often poor voltage regulation. The most common use of STATCOM is for voltage stability. It is a VSC (voltage source converter) based device, with the voltage source behind a reactor. A DC capacitor form the voltage source hence a STATCOM has very little active power capability. However, if a suitable energy storage device is connected across the DC capacitor its active power capability can be increased.

STATCOM can improve dynamic voltage control in transmission and distribution system. In distribution system it is called as DSTACOM (Distribution STATCOM). Chong A method is proposed [18] in which an electrical arc furnace(EAF) is a major flicker source that causes major power quality problems. In that, flicker mitigation techniques by using a CMC-based STATCOM was presented and verified through a transient network analyzer (TNA) system.

Generation 3 (G3):

This generation includes multifunctional devices like UPFC, UPFC and multifunctional DGs.

1. UPFC (Unified Power Flow Controller): UPFC concept was proposed by Guygyi in 1991. It is a combination of STATCOM and SSSC (Static Synchronous Series Compensator) coupled via a common dc link. The UPFC improves terminal voltage regulation, series capacitor compensation, and transmission angle regulation. UPFC consists of multi-functional VSCs with the objective of maintain the flow of power and also voltage regulation as a secondary function. Few methods like PQ decoupled are used to study the power improvement methodologies [22].

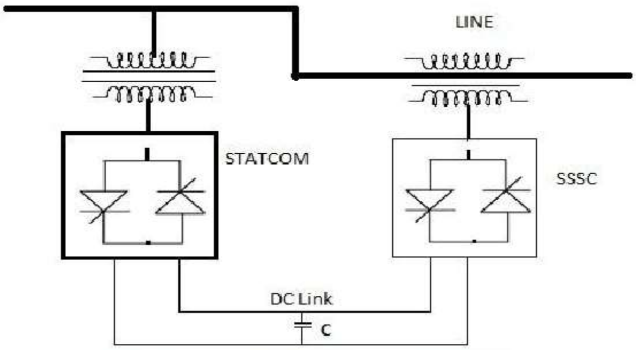

Fig.7: Basic Configuration of UPFC [21]

2. UPQC (Unified Power Quality Conditioner): The main function of UPQC is to compensate for supply voltage imbalance, reactive power, negative sequence current and harmonics. In other words, UPQC has the capability of improving the power quality at the point of installation on distribution network. UPQC is relatively a new device than others. It is a combination of DSTATCOM and DVR. It has two VSIs same as UPFC but one of the inverter is connected in series where as other is connected in shunt. Shunt compensator is used for compensating unsymmetrical harmonic components and other disturbances of load current. The series filter is used for compensation of voltage disturbance.

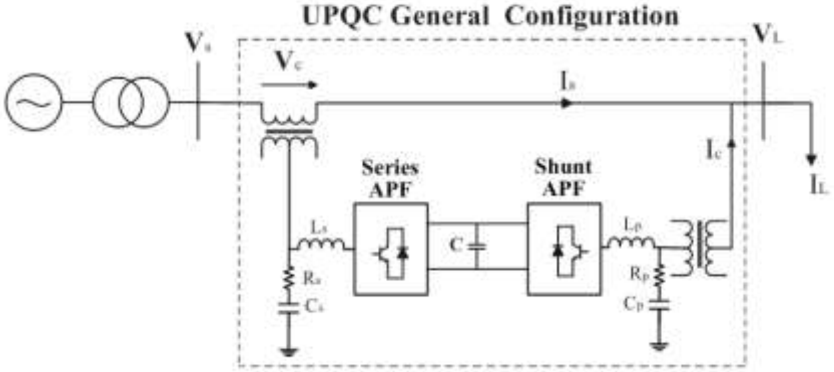

Fig.8: General Block Diagram of UPQC

The UPQC has various configurations depending upon the topology of converter (VSI, CSI), supply system (Right Shunt, Left Shunt, UPQC-Modular, UPQC–DG, etc), or type of compensation (UPQC-P for active power compensation, UPQC-Q for reactive power compensation, etc). UPQC can be further used with DGs to provide an uninterrupted power supply. Different type of configurations has different advantages and disadvantages for example VSI and CSI have their own merits and demerits [20]. The best advantage of UPQC is that it can eliminate the voltage and current harmonics simultaneously.

[20],[23-26] suggested various techniques for power quality improvement using UPQC. [27] suggested a technique for modeling of UPQC with PV arrays to improve power quality.

3. Multifunctional DG: The penetration of Renewable Energy Sources(RES) embedded with microgrids increased in last few years, hence the issue of power quality in distribution generation systems is equally important. The typical approach for these type of problems includes use of APF, PPF, SVC or other custom power devices. Multifunction DGs is a new and attractive approach for power quality improvements. [28] carried out an investigation on a modular multifunctional DGs based on a 3H-bridge converter and its control strategy. [29] proposed control model based on direct Lyapunov control (DLC) theory and gave a stable region for the proper operation of DGs at the time of integration with the power grid.

IV. Conclusion

Now electricity is not that much luxury article that was some 20 to 30 years ago but now its quality which affects the performance matters a lot. The increasing use of electronic equipment like programmable logic controllers (PLC), adjustable speed drives (ASD) led the nature of electric loads to a new level. In this paper different types of power quality mitigation devices are discussed. The Generation wise categorization of various devices gives us a picture from passive filters which are used for reduction in harmonic distortions to modern devices such as UPQC and UPFC. The ultimate reason we are concerned about power quality is economic value. The work in the area of power quality is still going on where the custom power devices like UPQCs are with smart grids for power quality improvement. Multifunctional DG units are used for the power quality enhancement of RES embedded grids.

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