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A Review of Power Quality Problems, Standards and Solutions

Pradeep Kumar
M.E Student, Department of Electrical Engineering,
National Institute of Technical Teachers' Training and Research, Chandigarh-160019
pradeep02334@gmail.com

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Abstract - *Power quality has become a major area of concern in present era due to the increase in modern sensitive and sophisticated loads connected to the Distribution System. The electrical devices or equipments are prone to failure when exposed to one or more power quality problems. The electrical device might be an electric motor, a transformer, a generator, a computer, a printer, communication equipment, or a household appliance reacts adversely to power quality issues depending on the severity of problems.*

This paper presents a review of the power quality problems, issues, related international standards and the solution techniques. Some power quality enhancement devices are also listed. It is necessary for engineers, technicians, and system operators to become familiar with power quality issues.

Key Words: Power quality issues, IEEE-519, Power Conditioning Devices, Voltage spikes, Frequency variation, voltage sag, Harmonics.

1.INTRODUCTION

Power Quality (PQ) related problems are of most concern nowadays. The widespread application of electronic equipments, like, information technology equipment, power electronic based equipments such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, are completely changing the nature of electric loads. The applications of such kind of electric loads are the major victims of power quality problems. Due to their non-linearity, such kind of electric loads cause disturbances in the voltage waveform.

This paper discusses the major power quality problems, related international standards and solutions based on an extensive number of publications.

2. TYPES OF POWER QUALITY PROBLEMS

There are several aspects of power quality problems due to which an electrical device may malfunction, fail prematurely or not operate at all. Some of the most common power supply problems and their likely effect on sensitive equipment.

2.1 Voltage fluctuations

Voltage fluctuations are caused by arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads. Consequences are under voltages, flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

2.2 Voltage dips and under voltage

Short duration under-voltages are called "Voltage Sags" or "Voltage Dips [IEC]". Voltage sag is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min. The main causes of voltage dips are fault in the system, starting of large loads. Excessive network loading, loss of generation, incorrectly set transformer taps and voltage regulator malfunctions, causes under voltage which indirectly lead to overloading problems as equipment takes an increased current to maintain power output (e.g. motor loads).

2.3 Voltage swell

Voltage swell is defined as an increase to between 1.1 and 1.8 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min. The major causes are Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during offpeak hours). Consequences are data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.

2.4 Very short interruption

Total interruption of electrical supply for duration from few milliseconds to one or two seconds causes ripping of protection devices, loss of information and malfunction of data processing equipment. Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network.

2.5 Long interruption

Long interruption of electrical supply for duration greater than 1 to 2 seconds causes stoppage of all equipment. The main fault causes are 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.

2.6 Harmonic distortion

Main Causes are electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC motor, all non-linear loads, such as power electronics equipment including adjustable speed drives (ASDs), switched mode power supplies, data processing equipment, high efficiency lighting. Consequences are increased probability in occurrence of resonance, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, and errors in measures when using average reading meters, nuisance tripping of thermal protections.

2.7 Voltage unbalance

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 are 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).Unbalancing results in negative sequence that is harmful to all three phase loads, particularly most affected loads are three-phase induction machines.

2.8 Voltage surges/spikes

Voltage rise that may be nearly instantaneous (spike) or takes place over a longer duration (surge). A voltage surge takes place when the voltage is 110% or more above normal. The most common cause is heavy electrical equipment being turned off. Possible Solutions are surge suppressors, voltage regulators, uninterruptable power supplies, power conditioners.

2.9 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. The effects on vulnerable electronic systems can include loss of data and burned circuit boards. Possible Solutions are using Surge Suppressors, Voltage Regulators, Uninterruptable Power Supplies, Power Conditioners.

2.10 Frequency variation

A frequency variation involves a change in frequency from the normally stable utility frequency of 50 or 60 Hz, depending on geographic location. This may be caused by erratic operation of emergency generators or unstable frequency power sources. For sensitive equipment, the results can be data loss, program failure, equipment lock-up or complete shutdown. Possible Solutions are using Voltage Regulators and Power Conditioners.

2.11 Brownouts

A brownout is a steady lower voltage state causes glitches, data loss and equipment failure. 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. Possible Solutions are using Voltage Regulators, Uninterruptable Power Supplies, and Power Conditioners.

2.12 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.

2.13 Noise

Superimposing of high frequency signals on the waveform of the power-system frequency caused by microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment, improper grounding etc. Consequences are disturbances on sensitive electronic equipment, usually not destructive, data loss and data processing errors.

2.14 Electrical line noise

Electrical line noise is defined as Radio Frequency Interference (RFI) and Electromagnetic Interference (EMI) and causes equipment to lock-up, and data error or loss. Sources of the problems include motors, relays, motor control devices, broadcast transmissions, microwave radiation, and distant electrical storms. Possible Solutions are using Voltage Regulators, Uninterruptable Power Supplies, and Power Conditioner.

3. POWER QUALITY STANDARDS

PQ problems are the worldwide issue. To minimize the PQ level some measures have been developed by International organizations for the utility to deliver the quality electric power to the end users. Standardization organizations like IEC, CENELEC, and IEEE have developed set standards for quality of electric power. In Europe, the most relevant standards in PQ are the EN 50160 (by CENELEC) and IEC 61000. The power quality standards developed by IEEE do not have such a structured and comprehensive set as compared to European power quality standard IEC. Main IEEE power quality standards are described in the ensuing sections.

3.1 IEEE 519

IEEE standard 519-1992 is titled as Recommended Practices and Requirements for Harmonic Control in Electric Power systems. The 1992 standard is a revision of an earlier IEEE work published in 1981 covering harmonic control. The basic themes of IEEE Standard 519 are twofold.

i. Electric utilities have the responsibility to produce a high quality supply in terms of voltage level and waveform.

ii. Utility consumers must limit the harmonic currents drawn from the line.

The responsibility of an electric utility is to deliver quality electric power to the end user consumers. The quality electrical power protects the electrical equipments from overheating, loss of life from excessive harmonic currents, and excessive voltage stress due to excessive harmonic voltage.

IEEE 519 lists the harmonic distortion limits at the point of common coupling. (PCC). The voltage distortion limits of 3 percent harmonic distortion for an individual frequency component and 5 percent for total harmonic distortion.

In IEEE standard 519, all of harmonic limits are based on the customer load mix and the location of sensitive & sophisticated equipments in the power system. Such PQ standards are not applied to particular equipment.

3.1.1 IEEE 519 Standard for Current Harmonics

i) General distribution systems [120 V-69 KV]: Current distortion limits are for odd harmonics. Even harmonics are limited to 25% of the odd Harmonic limits [1, 3, 5]. For all power generation equipment, distortion limits are those with $I_{SC}/I_L < 20$. I_{SC} is the maximum short circuit current at the Point of Common Coupling "PCC". I_L is the maximum fundamental frequency 15-or 30- minutes load current at point of Common Coupling "PCC. TDD is the total demand distortion (= THD normalized by I_L are shown in Table 2).

ii) General sub-transmission systems [69 Kv-161 kV]: The current harmonic distortion limits apply to limits of harmonics that loads should draw from the utility at the Point of Common Coupling "PCC". Note that the harmonic limits differ based on the I_{SC}/I_L rating, where I_{SC} is the maximum short circuit current at the PCC. I is the maximum demand load current at the PCC. I_{SC} is short circuit current presents at the PCC. The magnitude of I_{SC} current is determined by the size, impedance, and utility voltage connected to the Point of Common Coupling "PCC". I_L is the maximum demand load current, and it is measured at the PCC. The maximum harmonic current distortion level is shown in Table 3.

Table 2. Current Distortion Limits For Harmonics

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<25	h≥35	TDD (%)
<50	2.0	1.0	0.75	0.3	0.15	2.5
≥50	3.0	1.5	1.15	0.45	0.22	3.75

Table 3. Maximum Harmonic Current Distortion Level

I_{SC}/I_L	h<11	11≤h<17	17≤h<23	23≤h<25	TDD (%)
<20	4.0	2.0	1.5	0.6	5
20-50	7.0	3.5	2.5	1.0	8
50-100	10	4.5	4.0	1.5	12
100-1000	12	5.5	5.0	2.0	15
>1000	15	7.0	6.0	2.5	20

3.1.1 IEEE Standard For Voltage Harmonics

According to IEEE standard 519, for power system voltage limits below 69Kv, the harmonic distortion for an individual frequency is limited to 3% and 5% for Total Harmonic Distortion. The IEEE standard for voltage harmonics is shown in Table 4.

Table 4. Voltage Distortion Limits For Harmonics

Bus voltage	Individual V_h(%)	THDV(%)
V <69 kV	3.0	5.0
69≤V<161 kV	1.5	2.5
V≥161 kV	1.0	1.5

3.2. IEC 61000-3-2 and IEC 61000-3-4

3.2.1. IEC 61000-3-2 (1995-03)

This standard specified the limits for harmonic current emissions from the electrical and electronic equipments which having an input current up to and including 16 A per phase, and intended to be connected to public low-voltage distribution systems. The tests according to this standard are type tests [2,3,19].

3.2.2. IEC/TS 61000-3-4 (1998-10)

This standard specified for electrical and electronic equipments having a rated input current more than 16 A per phase and intended to be connected in public low-voltage ac distribution systems. The a.c distribution systems are of following types:

i. Single-phase, two or three wires distribution systems with a nominal voltage up to 240 V.

ii. Three-phase, three or four wires distribution systems and nominal voltage up to 600 V.

iii. Nominal frequency 50 Hz or 60 Hz.

On the basis of these recommendations, the service provider can asses equipment regarding harmonic disturbance and to decide whether the equipment is acceptable for connection in the electric power systems. European standards, IEC 61000-3-2 & 61000-3-4, placing current harmonic limits on equipments. These equipments are designed in order to protect the small consumer's equipment. The former is restricted to 16 A and latter extends the range above 16 A.

3.3. IEEE Standard 141-1993, Recommended Practice for Electric Power Distribution for Industrial Plants

A thorough analysis of basic electrical-system considerations is presented. Guidance is provided in design, construction, and continuity of an overall system to achieve safety of life and preservation of property; reliability; simplicity of operation; voltage regulation in the utilization of equipment within the tolerance limits under all load conditions; care and maintenance; and flexibility to permit development and expansion.

3.4. IEEE Standard 142-1991, Recommended Practice for Grounding of Industrial and Commercial Power Systems

This standard presents a thorough investigation of the problems of grounding and the methods for solving these problems. There is a separate chapter for grounding sensitive equipment.

3.5. IEEE Standard 446-1987, Recommended Practice fo1r Emergency and Standby Power Systems for Industrial and Commercial Applications

This standard is recommended engineering practices for the selection and application of emergency and standby power systems. It provides facility designers, operators and owners with guidelines for assuring uninterrupted power, virtually free of frequency excursions and voltage dips, surges, and transients.

3.6. IEEE Standard 493-1997, Recommended Practice for Design of Reliable Industrial and Commercial Power Systems

The fundamentals of reliability analysis as it applies to the planning and design of industrial and commercial electric power distribution systems are presented. Included are basic concepts of reliability analysis by probability methods, fundamentals of power system reliability evaluation, economic evaluation of reliability, cost of power outage data, equipment reliability data, and examples of reliability analysis. Emergency and standby power, electrical preventive maintenance, and evaluating and improving reliability of the existing plant are also addressed.

3.7. IEEE Standard 1100-1999, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment

Recommended design, installation, and maintenance practices for electrical power and grounding (including both power-related and signal-related noise control) of sensitive electronic processing equipment used in commercial and industrial applications.

3.8. IEEE Standard 1346-1998 Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment

A standard methodology for the technical and financial analysis of voltage sag compatibility between process equipment and electric power systems is recommended. The methodology presented is intended to be used as a planning tool to quantify the voltage sag environment and process sensitivity.

3.9. IEEE Standard 1159-1995, Recommended Practice for Monitoring Electric Power Quality

As its title suggests, this standard covers recommended methods of measuring power-quality events. Many different types of power-quality measurement devices exist and it is important for workers in different areas of power distribution, transmission, and processing to use the same language and measurement techniques. Monitoring of electric power quality of AC power systems, definitions of power quality terminology, impact of poor power quality on utility and customer equipment, and the measurement of electromagnetic phenomena are covered.

3.10. IEEE Standard 1250-1995, Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances

Computers, computer-like products, and equipment using solidstate power conversion have created entirely new areas of power quality considerations. There is an increasing awareness that much of this new user equipment is not designed to withstand the surges, faults, and reclosing duty present on typical distributions systems. Momentary voltage disturbances occurring in ac power distribution and utilization systems, their potential effects on this new, sensitive, user equipment, and guidance toward mitigation of these effects are described. Harmonic distortion limits are also discussed.

3.11. IEEE Standards Related to Voltage Sag and Reliability

The distribution voltage quality standard i.e. IEEE Standard P1564 gives the recommended indices and procedures for characterizing voltage sag performance and comparing performance across different systems. A new IEC Standard 61000-2-8 titled "Environment Voltage Dips and Short Interruptions" has come recently. This standard warrants considerable discussion within the IEEE to avoid conflicting methods of characterizing system performance in different parts of the world.

3.12. IEEE Standards Related to Flicker

Developments in voltage flicker standards demonstrate how the industry can successfully coordinate IEEE and IEC activities. IEC Standard 61000-4-15 defines the measurement procedure and monitor requirements for characterizing flicker. The IEEE flicker task force working on Standard P1453 is set to adopt the IEC standard as its own.

3.13. Standards related to Custom Power

IEEE Standard P1409 is currently developing an application guide for custom power technologies to provide enhanced power quality on the distribution system. This is an important area for many utilities that may want to offer enhanced power quality services.

3.14. Standards related to Distributed Generation

The new IEEE Standard P1547 provides guidelines for interconnecting distributed generation with the power system.

3.15. 420-2013 - IEEE Standard for the Design and Qualification of Class 1E Control Boards, Panels and Racks Used in Nuclear Power Generating Stations

This standard specifies the design requirements for new and/or modified Class 1E control boards, panels, and racks and establishes the methods to verify that these requirements have been satisfied. Methods for meeting the separation criteria contained in IEEE Std 384 are addressed. Qualification is also included to address the overall requirements of IEEE Std 323 and recommendations of IEEE Std 344.

3.16. IEEE Standard 384-2008 - IEEE Standard Criteria for Independence of Class 1E Equipment and Circuits

The independence requirements of the circuits and equipment comprising or associated with Class 1E systems are described. Criteria for the independence that can be achieved by physical separation and electrical isolation of circuits and equipment that are redundant are set forth. The determination of what is to be considered redundant is not addressed.

3.17.IEEE Standard C57.18.10-1998 – IEEE Standard Practices and Requirements for Semiconductor Power Rectifier Transformers

Practices and requirements for semiconductor power rectifier transformers for dedicated loads rated single phase 300 kW and above and three-phase 500 kW and above are included. Static precipitators, high-voltage converters for DC power transmission, and other nonlinear loads are excluded. Service conditions, both usual and unusual, are specified, or other standards are referenced as appropriate. Routine tests are specified. An informative annex provides several examples of load loss calculations for transformers when subjected to non-sinusoidal currents, based on calculations provided in the standard.

3.18. IEEE Standard C57.21-1990 -IEEE Standard Requirements, Terminology and Test Code for Shunt Reactors Rated Over 500 kVA

All oil-immersed or dry-type, single-phase or three-phase, outdoor or indoor shunt reactors rated over 500 kVA are covered. Terminology and general requirements are stated, and the basis for rating shunt reactors is set forth. Routine, design, and other tests are described, and methods for performing them are given. Losses and impedance, temperature rise, dielectric tests, and insulation levels are covered. Construction requirements for oil-immersed reactors and construction and installation requirements for dry-type reactors are presented.

4. POWER QUALITY SOLUTIONS

4.1. Power Conditioning Devices

The following devices play a crucial role in improving power quality strategy.

4.1.1 Transient Voltage Surge Suppressor (TVSS)

It provides the simplest and least expensive way to condition power. These units clamp transient impulses (spikes) to a level that is safe for the electronic load. Transient voltage surge suppressors are used as interface between the power source and sensitive loads, so that the transient voltage is clamped by the TVSS before it reaches the load. TVSS usually contain a component with a nonlinear resistance (a metal oxide varistor or a zener diode) that limits excessive line voltage and conduct any excess impulse energy to ground.

4.1.2 Filters

Filters are categorized into noise filters, harmonic filters (active and passive) etc. Noise filters are used to avoid unwanted frequency current or voltage signals (noise) from reaching sensitive equipment. This can be accomplished by using a combination of capacitors and inductances that creates a low impedance path to the fundamental frequency and high impedance to higher frequencies, that is, a low-pass filter. Harmonic filters are used to reduce undesirable harmonics. Passive filters consist in a low impedance path to the frequencies of the harmonics to be attenuated using passive components (inductors, capacitors and resistors).

4.1.3 Isolation Transformers

Isolation transformers are used to isolate sensitive loads from transients and noise deriving from the mains. The particularity of isolation transformers is a grounded shield made of nonmagnetic foil located between the primary and the secondary. Any noise or transient that come from the source in transmitted through the capacitance between the primary and the shield and on to the ground and does not reach the load. Isolation transformers reduce normal and common mode noises, however, they do not compensate for voltage fluctuations and power outages.

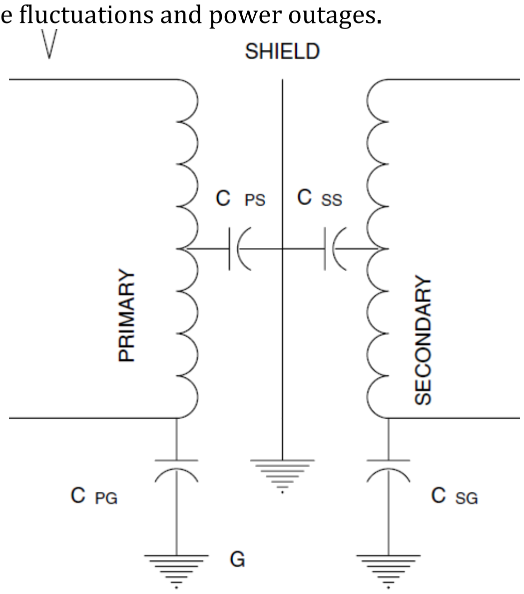

Fig-1: Noise attenuation by Isolation Transformer.

4.1.4 Voltage Regulator

Voltage regulators are normally installed where the input voltage fluctuates, but total loss of power is uncommon. There are three basic types of regulators:

i. **Tap Changers-** Designed to adjust for varying input voltages by automatically transferring taps on a power transformer.

ii. **Buck Boost-** Utilize similar technology to the tap changers except the transformer is not isolated.

iii. **Constant Voltage Transformer (CVT***)*-Also known as ferroresonant transformers. The CVT is a completely static regulator that maintains a nearly constant output voltage during large variations in input voltage.

4.1.5Uninterrupted Power Supply (UPS)

UPS systems provide protection in the case of a complete power interruption (blackout). They should be applied where *"down time"* resulting from any loss of power is unacceptable. UPS are designed to provide continuous power to the load in the event of momentary interruptions. They also provide varying degrees of protection from surges, sags, noise or brownouts depending on the technology used. There are three major UPS topologies each providing different levels of protection:

a) Off-Line UPS (also called Standby)

Low cost solution for small, less critical, stand-alone applications such as programmable logic controllers, personal computers and peripherals. Advantages of off-line UPS are high efficiency, low cost and high reliability.

b) Line-Interactive UPS

Line-Interactive UPS provides
highly effective power conditioning plus battery backup. Advantages are good voltage regulation and high efficiency. Disadvantages are noticeable transfer time and difficulty in comparing competing units.

c) True On-Line UPS

True On-Line UPS provides the highest level of power protection, conditioning and power availability. Advantages of the online UPS include the elimination of any transfer time and superior protection from voltage fluctuations.

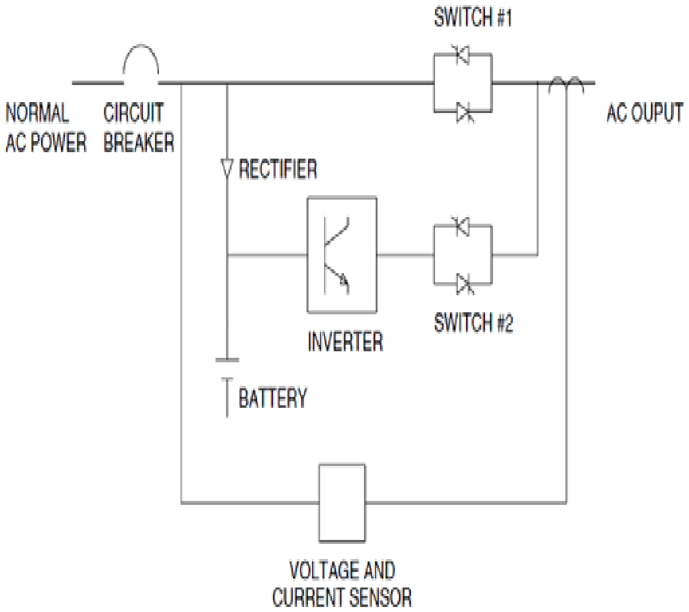

Fig- 2: Offline UPS System

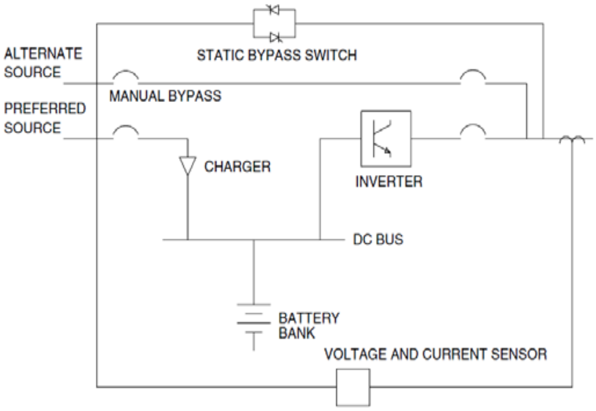

Fig-3: Online UPS system

4.1.6 Dynamic Static Compensator D-STATCOM

The D-STATCOM is one of the most effective Custom power devices used in a distribution network. It is a three-phase and shunt connected power electronics based device which is connected near the load at the distribution systems. The schematic diagram of a D-STATCOM (Distribution Static Compensator), is shown in Figure-6. It consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

The voltage-source converter (VSC) connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power

2. Correction of power factor.

3. Elimination of current harmonics.

A voltage-source converter (VSC) is a power electronic device as shown in Fig 4. The function of a VSC is to generate a sinusoidal voltage with minimal harmonic distortion from a DC voltage and connected to AC distribution line through coupling transformer. The DC side of the voltage-source converter (VSC) is connected to a DC capacitor.

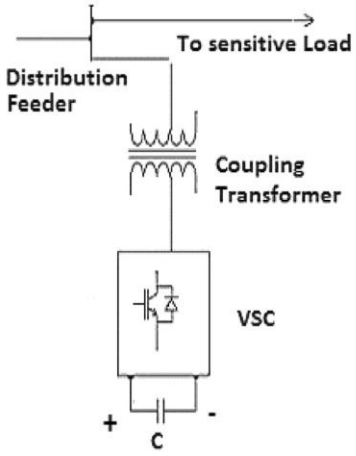

Fig.4. The Schematic diagram of a DSTATCOM (Distribution Static Compensator)

The AC terminals of the converter are connected to the Point of Common Coupling (PCC) through an inductance as shown in Fig. 4, such inductance could be a filter inductance or the leakage inductance of the coupling transformer. A dc capacitor could be charged by a battery source, or could be precharged by the converter itself. The output voltage of the voltage-source converter VSC is compared with AC bus voltage. If the voltage of a converter is equal to the AC terminal voltage, the reactive power exchange is zero. When the AC terminal voltage magnitude is greater than that of voltage-source converter (VSC) voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The amount of reactive power flow is proportional to the difference in the two voltages.

If the D-STATCOM has a DC source or energy storage device on its DC side, it can supply real power to the distribution networks. The active power flow is controlled by the angle between the ac terminal and voltage-source converter (VSC) voltages. When phase angle of the AC terminal voltage leads the voltage-source converter (VSC) phase angle, the D-STATCOM absorbs the real power from the distribution networks. If the phase angle of the AC terminal voltage lags the voltage-source converter (VSC) phase angle, the D-STATCOM supplies real power to distribution networks. The DSTATCOM operates in both current and voltage control modes.

4.1.7 Unified Power Quality conditioner (UPQC)

The Unified Power Quality Conditioner (UPQC) is a custom power device that consists of two voltage source inverters (VSI) is connected to a dc energy storage capacitor.

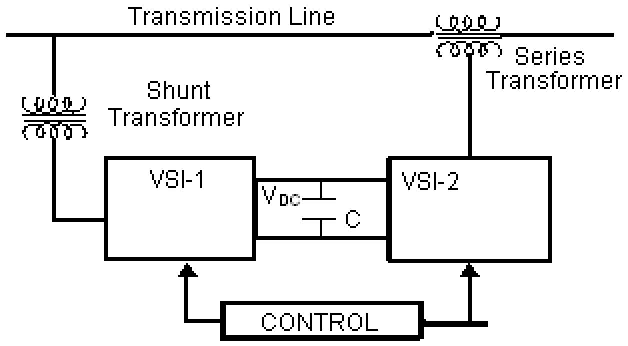

Fig.5. Schematic diagram of a Unified Power Quality conditioner (UPQC).

The schematic diagram of a Unified Power Quality conditioner is shown in Fig.9. A UPQC, combines the operations of a Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Regulator (DVR) together. This combination allows a simultaneous compensation of the load currents and the supply voltages, so that compensated current drawn from the network and the compensated supply voltage delivered to the load are sinusoidal and balanced. It places in the distribution system to reduce the disturbances that impact on the performance load. UPQC is the only multi functioning device which can reduce several problems power quality problems.

4.1.8 Thyristor based Static switch

The static switch is a versatile device for switching a new element into the circuit when voltage support is needed. To correct quickly for voltage spikes, sags, or interruptions, the static switch can be used to switch in capacitor, filter, alternate power line, energy storage system etc. It protects against 85% of the interruptions and voltage sags.

4.1.9 Motor Generator (MG) Set

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 over voltages and frequency fluctuations. Motor generators are consists of an electric motor driving a generator with coupling through a mechanical shaft. This solution provides complete decoupling from incoming disturbances such as voltage transients, surges and sags.

4.1.10 Static VAR compensator (SVC)

Static VAR compensators (SVC) use a combination of capacitors and reactors to regulate the voltage quickly. Solidstate switches control the insertion of the capacitors and reactors at the right magnitude to prevent the voltage from fluctuating.

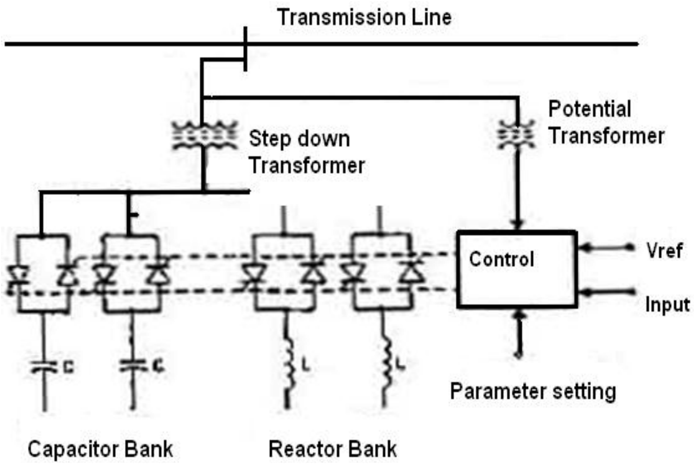

Fig-6 Static VAR compensator using TCR and TSC.

It is normally applied to transmission networks to counter voltage dips/surges during faults and enhance power transmission capacity on long.

4.2 Energy Storage System

4.2.1 Flywheels

A flywheel is an electromechanical device that couples a rotating electric machine (motor/generator) with a rotating mass to store energy for short durations. The motor/generator draws power provided by the grid to keep the rotor of the flywheel spinning. During a power disturbance, the kinetic energy stored in the rotor is transformed to DC electric energy by the generator, and the energy is delivered at a constant frequency and voltage through an inverter and a control system. Advanced flywheels constructed from carbon fiber materials and magnetic bearings can spin in vacuum at speeds up to 40,000 to 60,000 RPM. The stored energy is proportional to the moment of inertia and to the square of the rotational speed. High speed flywheels can store much more energy than the conventional flywheels. Flywheels typically provide 1-100 seconds of ride-through time, and back-up generators are able to get online within 5-20 seconds.

4.2.2 Super capacitors

Super capacitors (also known as ultra capacitors) are DC energy sources and must be interfaced to the electric grid with a static power conditioner, providing energy output at the grid frequency. A super capacitor provides power during short duration interruptions or voltage sags. Medium size super capacitors (1 M Joule) are commercially available to implement ride-through capability in small electronic equipment, but large super capacitors are still in development, but may soon become a viable component of the energy storage field. Capacitance is very large because the distance between the plates is very small (several angstroms), and because the area of conductor surface (for instance of the activated carbon) reaches 1500-2000 m2/g (16000-21500 ft2/g). Thus, the energy stored by such capacitors may reach 50-60 J/g.

4.2.3 Super Conducting Magnetic Energy Storage (SMES)

A magnetic field is created by circulating a DC current in a closed coil of superconducting wire. The path of the coil circulating current can be opened with a solid-state switch, which is modulated on and off. Due to the high inductance of the coil, when the switch is off (open), the magnetic coil behaves as a current source and will force current into the power converter which will charge to some voltage level. Proper modulation of the solid-state switch can hold the voltage within the proper operating range of the inverter, which converts the DC voltage into AC power. Low temperature SMES cooled by liquid helium is commercially available. High temperature SMES cooled by liquid nitrogen is still in the development stage and may become a viable commercial energy storage source in the future due to its potentially lower costs. SMES systems are large and generally used for short durations, such as utility switching events.

5. IMPROVE POWER QUALITY

5.1. Grounding & Bonding Integrity

Computer based industrial system performance is directly related to the quality of the equipment grounding and bonding. If the grounding and bonding is incorrectly configured, poor system performance is the result. Grounding is one of the most important and misunderstood aspects of the electrical system. It is essential to differentiate the functions of the grounded conductor (neutral) from the equipment grounding system (safety ground). The safety ground protects the electrical system and equipment from super-imposed voltages caused by lightning or accidental contact with higher voltage systems. It also prevents static charges build-up. The safety ground establishes a “zero-voltage” reference point for the system. The safety ground must be a low impedance path from the equipment to the bonding point to the grounding electrode at the service entrance. This allows fault currents high enough to clear the circuit interrupters in the system preventing unsafe conditions.

The grounded conductor (neutral) is a current carrying conductor which is bonded to the grounding system at one point.

Grounding this conductor limits the voltage potential inside the equipment in reference to grounded parts. Neutral and ground should only be bonded together at the service entrance or after a separately derived source. One of the most common errors in a system is bonding the neutral to ground in multiple locations. Whether intentional or unintentional, these ‘extra’ bonding points should be identified and eliminated. Proper grounding and bonding minimizes costly disturbances.

5.2. Proper Wiring

An overall equipment inspection is crucial to ensure proper wiring within a facility. The entire electrical system should be checked for loose, missing or improper connections at panels, receptacles and equipment. Article 300 of the National Electrical Code cover wiring methods and should be followed to ensure safe and reliable operation. There are many types of commonly available circuit testers that can be used to check for improper conditions such as reversed polarity, open neutral or floating grounds. Make certain to isolate panels feeding sensitive electronic loads from heavy inductive loads, or other electrically noisy equipment such as air compressors or refrigeration equipment. Also check neutral and ground conductors to make sure they are not shared between branch circuits.

5.3. Power Disturbances

Voltage fluctuations and noise are common power disturbances present in any electrical environment that directly affect electronic equipment. These disturbances exist in numerous forms including transients, sags, swells, over voltages, under voltages, harmonics, outages, frequency variations and high frequency noise. Harmonic distortion has emerged as significant problem due to the increased use of electronic equipment. This electronic equipment draws current that is not linear to the voltage waveform. This non-linear current can cause high neutral current, overheated neutral conductors, overheated transformers, voltage distortion and breaker tripping. Loads such as solid-state controls for adjustable speed motors, computers and switched mode power supplies are sources of non-linear currents. The Information Technology Industry Council (ITIC) has revised the CBEMA curve in 2000. This curve is used to define the voltage operating envelope within which electronic equipment should operate reliably. Equipment should be able to tolerate voltage disturbances in the "no interruption" region of the chart. When the voltage disturbance is in the "no-damage" region, the equipment may not operate properly, but should recover when voltage returns to normal. If voltages reach the "prohibited region," connected equipment may be permanently damaged. Expensive equipment should be protected from voltages in the prohibited region. Processes which require high reliability should be protected from both the prohibited and no-damage regions.

6. Conclusion

The availability of electric power with high quality is crucial for the running of the modern society. If some sectors are satisfied with the quality of the power provided by utilities, some others are more demanding. To avoid the huge losses related to PQ problems, the most demanding consumers must take action to prevent the problems. Among the various measures, selection of less sensitive equipment can play an important role. This paper presented a review of the power quality problems, issues, and related international standards. This paper will help research workers, users and suppliers of electrical power to gain a guideline about the power quality.

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AUTHOR

Pradeep Kumar received the B.Tech degree in Electrical Engineering from Uttar Pradesh Technical University, Lucknow. He is Master of Engineering (Instrumentation and Control) Final year student, Department of Electrical Engineering, National Institute of Technical Teachers' Training and Research, Chandigarh, India. His research interests include, power quality, special machines, Power Electronics.