Power Quality Problems and Solutions: An Overview

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Abstract: Power quality is one of the major concerns and emerging issues in the present era. With increasing quantities of non-linear loads being added to electrical systems, it has become necessary to investigate the power quality issues as all electrical devices are prone to failure when exposed to one or more power quality problems. This paper highlights comprehensive review of the power quality problems, effect of power quality problems in different apparatuses and methods for its correction. Some power quality enhancement devices are also discussed. This paper will be very much helpful for engineers, technicians, designers, researchers and system operators as it is necessary for them to become familiar with power quality issues.

Keywords: Power Quality (PQ), Harmonic, Voltage Sag, UPQC, DVR, SVC, UPS

1. Introduction

Power distribution systems, ideally, should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [1]. However, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies an the purity of the waveform of supplies is lost. Apart from nonlinear loads, some system events, both usual (e.g. capacitor switching, motor starting) and unusual (e.g. faults) could also inflict power quality (PQ) problems[2].

2. Why Power Quality is Important?

Along with technology advance, the organization of the worldwide economy has evolved towards globalization and the profit margins of many activities tend to decrease. The increased sensitivity of the vast majority of processes (industrial, services and even residential) to PQ problems turns the availability of electric power with quality a crucial factor for competitiveness in every activity sector. The most critical areas are the continuous process industry and the information technology services [3]. The performance of electronic devices is directly linked to the power quality level. quality phenomenon or power quality disturbance can be defined as the deviation of the voltage and the current from its ideal waveform. Faults at either the transmission or distribution level may cause voltage sag or swell in the entire system or a large part of it. Also, under heavy load conditions, a significant voltage drop may occur in the system. Voltage sag and swell can cause sensitive equipment to fail, shutdown and create a large current unbalance. These effects can incur a lot of expensive from the customer and cause equipment damage. So , in order to provide uninterrupted power to the service sectors as well as others for economic growth and prevent equipment damage with varying voltage level and frequency , undoubtedly power quality improvement is utmost important.

3. Power Quality and its Indices

Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment”[4]. Power quality imposes pre specified quality and reliability of supply. This pre-specified quality may contain a combination of specifications of the following: low phase unbalance, no power interruptions, low flicker at the load voltage, and low harmonic distortion in load voltage, magnitude and duration of over voltages and under voltages within specified limits, acceptance of fluctuations, and power factor of loads without significant effect on the terminal voltage. The following symptoms are indicators of Power Quality problems:

- Piece of equipment malfunctions at the same time of day.
- Circuit breakers trip without being overloaded.
- Equipment fails during a thunderstorm.
- Automated systems stop for no apparent reason.
- Electronic systems fail or fail to operate on a frequent basis.
- Electronic systems work in one location but not in another location

4. Power Quality Standards

Power quality is a worldwide issue and its related standards [4] being used by researchers, designer and practitioner to improve power quality are given below:

- IEEE-519 provides recommended practices and requirements for harmonic control in electric power systems, established limits on harmonic currents(table 1) and voltages(table 2) at the point of common coupling (PCC), or point of metering.
5. Power Quality Problems and Effect

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.

5.1 Voltage fluctuations

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 [1].

5.2 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 [5].

5.3 Voltage dips and under voltage

Short duration under-voltages are called “Voltage Sags” or “Voltage Dips [IEC]”. Voltage sag [6], [7] is a reduction in the supply voltage magnitude followed by a voltage recovery after a short period of time. The major cause 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) [6].

5.4 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 [8].

5.5 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 [8].

5.6 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 [8].
5.7 Brownouts

A brownout [9] 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 [9].

5.8 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 [10].

5.9 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 [11]. Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network.

5.10 Long interruption

Long interruption of electrical supply for duration greater than 1 to 2 seconds causes stoppage of all equipment [1]. 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.

5.11 Voltage swell

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. The main causes are Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours). Consequences are data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high [11].

5.12 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 [11]. 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.

5.13 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 [12].

5.14 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 [13].

6. Power Quality Solutions

6.1 Power Conditioning Devices

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

6.1.1 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 [14].

6.1.2 Filters

Filters are categorized into noise filters, harmonic [15] 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).

6.1.3 Isolation Transformers

Isolation transformers [16] 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 [16].

![Image of Isolation Transformer](image_url)

**Figure 1:** Noise attenuation by Isolation Transformer

### 6.1.4 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:

- **Tap Changers**- Designed to adjust for varying input voltages by automatically transferring taps on a power transformer.
- **Buck Boost**- Utilize similar technology to the tap changers except the transformer is not isolated.
- **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.

### 6.1.5 Uninterrupted 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 [14].

There are three major UPS topologies each providing different levels of protection:

- **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.
- **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.
- **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.

![Image of Offline UPS System](image_url)

**Figure 2:** Offline UPS System

![Image of Online UPS System](image_url)

**Figure 3:** Online UPS system

### 5.1.6 Dynamic Voltage Restorer (DVR)

A dynamic voltage restorer (DVR) acts like 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 through a voltage converter [17].

![Image of DVR Topology](image_url)

**Figure 4:** Topology of dynamic voltage restorer (DVR)

### 6.1.7 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 [14] 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.

6.1.8 Static VAR compensator (SVC)
Static VAR compensators (SVC) use a combination of capacitors and reactors to regulate the voltage quickly. Solid-state switches control the insertion of the capacitors and reactors at the right magnitude to prevent the voltage from fluctuating. It is normally applied to transmission networks to counter voltage dips/surges during faults and enhance power transmission capacity on long [14].

![Figure 5: Static VAR compensator using TCR and TSC](image)

6.1.9 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 [18].

6.1.10 Unified Power Quality Conditioner (UPQC)
The UPQC employs two voltage source inverters (VSI) that is connected to a dc energy storage capacitor. 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 [18].

![Figure 6: Basic Structure of UPQC](image)

6.2 Energy Storage System

6.2.1 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 fibre 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 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 [19].

6.2.2 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 MJoule) 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 [17].

6.2.3 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 [19].
7. Other Recommendations

Some practices to check/mitigate power quality problems are recommended below:

7.1 Proper Grounding and Bonding

A recent survey of Power Quality experts indicates that 50% of all Power Quality problems are related to grounding, ground bonds, and neutral to ground voltages, ground loops, ground current or other ground associated issues[4]. 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.

7.2 Proper Wiring

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 (NEC) 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.

7.3 Safe Operating Zone

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.

7.4 Proper designing of the Load equipment.
7.5 Proper designing of the power supply system.
7.6 Application of passive, active and hybrid harmonic filters, FACTS devices.
7.7 Application of voltage compensators and different power conditioning devices at different stages like generation, transmission and distribution system as per requirement and suitability.
7.8 Reliability on standby power.
7.9 Adoption of hybrid energy system with optimal distributed generations.

8. Conclusions

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 will demand more. When even the most robust equipment is affected, then other measures must be taken, such as installation of restoring technologies, distributed generation or an interface device to prevent PQ problems. Coordination with existing industry practices and international harmonic standards is also considered in this paper. Optimized use of power quality enhancement devices is required as the cost, complexity, flexibility of various techniques is different and this optimization issue is under research to find an efficient answer to the power quality problems. So, undoubtedly, this paper has a good future scope and will help research workers, users and suppliers of electrical power to gain a guideline about the power quality.
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Author Profile

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