Power Quality Issues, Effects, Standards and Their Mitigation Solutions

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Abstract* - This paper presents review on the existing power quality problems headed with modern electrical energy utilization. It describes unlike power quality concomitant issues in details while also dealing with its related causes, consequences and remedial solution and techniques. It has become necessarily important to protect electrical equipment from being damaged and this can possible only by establishing the limiting criteria for different operating equipment's and through different research process The standards which governs modern power industry from its manufacturing stage to operation comportment. Various national and international organizations have their standards for their safe usages. Among various IEEE standards mostly followed power industry to different part with some other, the paper gives out some standards relating to enhance the safe operation of the system with respect to its problems while describing its importance. The latest living idea of making life easier using technology severely depends mostly on application of power electronic and non-linear devices, which are being added to the electrical system rapidly. This paper has also discussed and described the important solution methods for protecting and safeguarding the power system.

Keywords: Power Quality (P.Q), Deregulation, Non-Linear Load, Total Harmonic Distortion, and International Standards..

I. INTRODUCTION

Electrical energy as being the most popular and efficient form of energy with the modern society heavily dependent on electrical supply. The life cannot be imagined without the supply of electricity, at the same time quality cannot be improvised for continuity to maintain of electrical supply for efficiently functioning utility and end user equipment. In the past most power consuming equipment tolerated some distortion. But for today scenario commercial and industrial load demands high quality uninterrupted power for efficiently and economically working. The Deregulation of Electric power industry has made the quality of power delivered the major topic with increasing importance. It has not remained only an issue for the investigator of the technical group but an important problem related from basic of system design to the user group of power. Thus maintaining the good quality power an utmost importance for the present and future development.

Power quality problem occurs when the alternating-voltage power source's 50/60 HZ sine waves is distorted or any problem manifested in voltage, current or frequency deviation that result in failure or missed operation of utility or end user equipment. **[1]** These distorted waveform affects the performance and lifetime of the user equipment's end resulting in an economic loss to the system and the society. The quality of electrical power delivered is characterized by two factors namely "continuity of supply" and "Quality of voltage". As per IEEE statement power quality is as ability of a system or equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. **[1]**

Power quality issues has increased nowadays with the widespread use of the electronic equipment such as information technology equipment's, Adjustable speed drives (ASD), programming logic controller (PLC), Energy efficient lighting led to change in nature of electrical loads. Due to their non-linearity in operation all these loads causes disturbance in the voltage waveform.

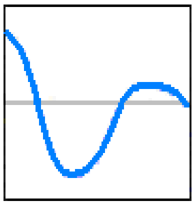
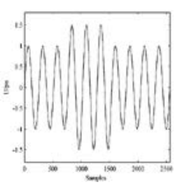
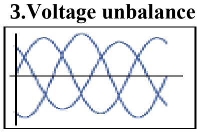
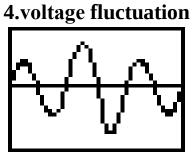
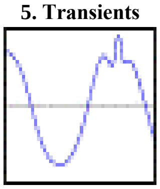
Although many efforts have been made by the utilities provider but some consumers require a level of PQ higher than the level provided by the modern electrical network. This implies that some measures must be taken in order to achieve higher level of power quality.

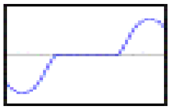
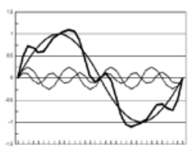
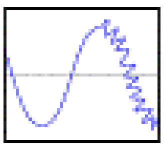
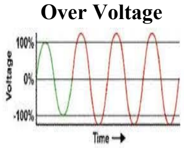
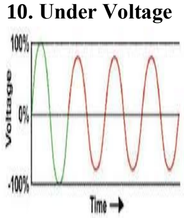
II. POWER QUALITY PROBLEMS

There are many reasons by which the power quality is affected. The occurrence of such problems in power system network is almost indispensable. Therefore, to maintain the quality of power care must be taken that suitable devices are kept in operation to prevent the consequences of these different problems.

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. **[1,7,8]** The

TABLE: -1 POWER QUALITY DISTURBANCES, CAUSE, AND MEASURE

POWER QUALITY PROBLEMS	DESCRIPTION	CAUSES	EFFECTS AND CONSEQUENCES	POWER CONDITIONING EQUIPMENTS
1.Voltage sag 	A decrease in RMS voltage or current at the power frequency for durations of 0.5 cycles to 1 min. Typical are 0.1 to 0.9 PU. The voltage sag is characterized by its magnitude, duration and phase angle jump.	Faults on transmission or distribution network (most of the times on parallel feeders), Faults in consumer's installation, Connection of heavy loads, start-up of large motors which draws heavy loads and sudden increase in the load connected to the system.	Malfunction of electronic equipment's, information technology equipment namely microprocessor-based control systems (PCs, PLCs, ASDs, etc.) that may lead to a process stoppage, Tripping of contactors and electromechanical relays, Disconnection of running equipment's and loss of efficiency in electric rotating machines Etc.	• M-G Sets. • SVC . • Magnetic Synthesizers: • Uninterrupted power supplies. • SMES (Superconducting magnetic energy storage).
2.voltage swell 	RMS voltage variations that exceed 110 % of the nominal voltage and last for less than 1 minute.	Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours), energization of a capacitor bank, Abrupt interruption of current and single line to ground fault are the main caused of voltage swell.	Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.	• Constant voltage transformer (CVT) • Dynamic voltage restorer (DVR)
3.Voltage unbalance 	Voltage deviation in each phase from the average value of all the three phase.	Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases system (this may be also due to a fault).	Unbalanced systems imply the existence of a negative sequence that is harmful to all three- phase loads, The most affected loads are three-phase induction machine.	• Voltage regulators. • Ferro resonant transformers.
4.voltage fluctuation 	Rapid changes in voltage within the allowable limits of voltage magnitude of 0.95 to 1.05 nominal voltage.	Devices such as electric arc furnaces and welding m/c that have continuous, rapid changes in load current cause voltage fluctuations.	Incandescent lights blink rapidly and thus referred as "flicker." Change in light intensity occurs at frequencies of 6 to 8 Hz visible to the human eye and can cause people to have headaches, irritable also result sensitive equipment to malfunction.	• Voltage regulators. • Ferro resonant transformers.
5. Transients 	Momentary changes in voltage and current signals over a short period of time. Categorized by sudden increase or Decrease in voltage or current as impulsive or oscillatory.	Arcing between the contacts of the switches, Sudden switching of loads, Poor or loose connections, Lightening strokes, power factor correction capacitors, disconnection of heavy loads etc.	Electronics devices are affected and show wrong results, Motors run with higher temperature, Failure of ballasts in the fluorescent lights, Reduce the efficiency and lifetime of equipment	• Surge arrester. • Filters. • Isolation transformers.
POWER QUALITY PROBLEMS	**DESCRIPTION**	**CAUSES**	**EFFECTS AND CONSEQUENCES**	**POWER CONDITIONING EQUIPMENTS**

6. Interruption 	A complete loss of voltage (Drop to less than 10 % of nominal voltage) in on or more phases. (Long and Short interruption)	Opening of an automatic re-closure, lightening strokes etc. Fault in power system network, Human error, improper functioning of proper equipment's.	The data storage can get affected; malfunctioning of the equipment can be seen in like-PLC, ASD'S and many more. This type of interruption leads to the stoppage of power completely for a period of time until the fault is cleared.	• Energy storage technologies. • UPS. • Backup generators.
7. Harmonic Distortion 	Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine waves with different magnitude and phase, having frequencies that are in integral multiples of power-system frequency.	Electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors. Modern sources: all non-linear loads such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.	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, errors in measures when using average reading meters, nuisance tripping of thermal protections.	• Active and passive filters. • Transformers with cancellation of zero sequence components.
8. Noise 	Superimposing of high frequency signals on the waveform of the power-system frequency.	Electromagnetic interferences provoked by Hertz in waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, electronic equipment. Improper grounding.	Disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors.	• Static VAR systems.
9. Long Duration Over Voltage 	The RMS voltage variation that exceeds 110 % of the nominal voltage. The duration is longer then 1 minute.	The major cause of overvoltage is switching of capacitor bank and disconnection of heavy loads or dropping of loads or insetting of voltage setting on the tap changer transformer.	Over-voltage results with shortening the life of lighting filaments and motors.	• Using inductors during light load conditions and correctly setting trans- former taps.
10. Under Voltage 	Voltage drops below 90 % of the nominal voltage for more than 1 minute and sometimes referred to as "brownouts,"	Too much load on the utility's system, during very cold or hot weather, or the loss of a major transmission line serving a region can cause under voltages, Overloading inside an end user's own distribution system Sometimes utilities deliberately cause under voltages to reduce the load during heavy load conditions.	Under voltages can cause sensitive computer equipment to read data incorrectly and motors to stall and operate inefficiently.	• Utilities can prevent under voltages by building more generation and transmission lines. Figure

Determining the exact problems requires sophisticated electronic test equipment. The following common symptoms are indicators of Power Quality problems: -

- Unexplained equipment trips or shutdowns
- Occasional equipment damage or component failure
- Erratic control of process performance
- Random lockups and data errors
- Power system component overheating
- Equipment fails during a thunderstorm.
- Electronic system works in one location but not in the other.

List of different preceding P.Q problem with their relative cause and their possible consequence is illustrated though **(TABLE-1)** mentioned above.

III. EFFECTS OF POOR POWER QUALITY

The effect of power quality problems can be observed with the distortion in the voltage waveform of the power source sine wave, amplitude from an established reference level, or a complete interruption from the normal operation of devices. Power quality problems basically starts at four different levels of the system delivering electric power first includes Power plants and entire area transmission system, second concludes Transmission lines, major substations where as third deals with distribution substations, primary and secondary power lines and distribution transformers with last includes service equipment and building wiring. The disturbance can be caused by sag, swell, harmonics in the current or by any events in the main voltage supply system. The disturbance can vary from a fraction of cycle (milliseconds) to great durations (seconds to hours) in the voltage supplied by the source.

The disturbances to the system resulting with different costs of PQ that heavily depends on the sensitivity of equipment used with several factor like business area of the activity, equipment severity, and other relevant factors found in the facilities and market conditions, among other, also influence the costs of PQ problems. Here listed some of them.

IV. POWER QUALITY COST EVALUATION

The costs directed by poor power quality can be subcategorised into different form such as:-

A) Direct costs: **-** The costs that directly attributable to the disturbance. These costs include the damage in the equipment, loss of production, loss of raw material, salary costs during non-productive period and restart costs. In the IEEE Orange Book [5], the point is made that any production losses due to power interruptions in industrial plants, operating at 100% efficiency, will result in the direct loss of the profit of the item or service being derived from the facility. Sometimes, during the non-productive period some savings are achieved, such as energy savings, which must be subtracted to the costs. Some disturbances do not imply production stoppage, but may have other costs associated, such as reduction of equipment efficiency and reduction of equipment lifetime.

B) Indirect costs: **-** Sometimes called Facilities and Administrative (F&A) Costs or Overhead. These costs are very hard to evaluate. Due to some disturbances and non-productive periods, one company may not be able to accomplish the deadlines for some deliveries and loose future orders. Investments to prevent power quality problems may be considered an indirect cost.

C) Non-material inconvenience: - Some inconveniences due to power disturbance cannot be expressed in money, such as not listening to the radio or watch TV. The only way to account these inconveniences is to establish an amount of money that the consumer is willing to pay to avoid this inconvenience**. [9,10]**

Different Costs include field service warranty work, manufacturing interruptions, loss of productivity, loss of revenue, decreased competitiveness, lost opportunities, product damage, wasted energy and decreased equipment life. As many of these power quality cost elements can be the key factors in determining of the costs for action as well as inaction, following are an examples that define these parameters:

- Field service cost
- Manufacturing cost
- Productivity cost
- Loss of revenue
- Decrease competiveness
- Loss of opportunity
- Product damage
- Wastage energy
- Decreased equipment life

A) Estimated Costs

Several studies have been made to evaluate the costs of PQ problems for consumers. The assessment of an accurate value is nearly impossible so all these studies are based on estimates. Some equations have been developed. **[1,2,9]** To identify rough estimates of costs due to power disturbances on processes, from cash flow perspective. Upfront identifiable and hidden costs that need to be quantified should include the following:

Total Cost of a Power Disturbance (TCPD) (A + B + C + D)

A =Cost of labour for employees affected.

B= Service or product loss due to power disturbance.

C =Cost of restart.

D= Hidden costs.

V. POWER QUALITY STANDARDS

Power quality has always been as important as its need. However for many years the equation defining power quality was simple:

POWER QUALITY= RELIABILITY

As the customer loads were linear in nature so as when sinusoidal voltage was supplied, they drew sinusoidal current. But as the year passed the loads to the system changed as with customers non-inconvenience and for the ease in operation. The two major changes in the characteristics of customer loads and systems have completely changed the nature of the power quality equation:

- The first is the sensitivity of the loads.
- The second is the fact that these sensitive loads are interconnected in extensive networks and automated processes.

The main organizations responsible for developing power quality standards in the United States include following: Institute of Electrical and Electronics Engineers (IEEE), American National Standards Institute (ANSI), Electric Power Research Institute (EPRI), National Institute of Standards and Technology (NIST), National Fire Protection Association (NFPA), National Electrical Manufacturers Association (NEMA), and Underwriters Laboratories (UL). Outside the United States, the primary organizations responsible for developing international power quality standards include the following: International Electro technical Commission (IEC), Enormous, and ESKOM for South African standards.

In order to help the power quality industry, comparing the results of power quality measurements from different instruments, the IEEE developed IEEE Standard 1159-1995 copyright © 1995," Recommended Practice for Monitoring Electric Power Quality" defining various power quality terms and categorizes IEEE standards by the various power quality topics of grounding, powering, surge protection, harmonics, disturbances, mitigation equipment, telecommunications equipment, noise control, utility interface, monitoring, load immunity, and system reliability. **Table -2** provides a summary of the various types of IEEE power quality standards. **[1]**

TABLE: -2, IEEE Standards 1159-1995

Topic	**Relevant standards**
Voltage Sag	IEEE 1139,1100,1250
Voltage Swell	IEEE 1159
Grounding	IEEE 446, 141, 142, 1100
Powering	IEEE 141, 446, 1100, 1250
Surge protection	IEEE C62, 141, 142
Harmonics	IEEE C57, 110, 519,
Disturbances	IEEE 1100, 1159, 1250
Mitigation equipment	IEEE 446, 1035, 1100; 1250
Telecommunication equipment	IEEE 487, 1100
Noise control	IEEE 518, 1050
Utility interface	IEEE 446, 929, 1001, 1035
Monitoring	IEEE 1100, 1159
Load immunity	IEEE 141, 446, 1100, 1159, P1346
System reliability	IEEE 493

VI. SOLUTION TECHNIQUES

The problem of power quality arise at various different levels: transmission, distribution, and on the end-user sites. The mitigation of these fascinating problems can be attended through various processes at different levels:-

- Designing the electrical system from causing the disturbances.
- Analysing the P.Q problems so to determine its cause and solutions.
- Identifying the medium transmitting the disturbances to reduce the effect of that medium.
- Treating the symptoms of P.Q problem by installing power-conditioning equipment's.

The power conditioning equipment's necessarily reduces/eliminates the power quality effect and provides protection against power quality. Depending upon the equipment's and its locations it provides a barrier between electrical disturbances and equipment's. Equipment's like Uninterruptible power supplies (UPSs), line conditioners, surge suppressors, isolation transformers, passive filters, active filters, hybrid filters, superconducting magnetic energy storage (SMES), dynamic voltage restorers (DVRs), constant-voltage transformers (CVTs), and various types of motor-generator sets. The most effective and popular conditioning equipment of all is surge suppresser.

A. SURGE SUPPRESSORS:

The most commonly used device protecting the sensitive and costly equipment's. It protects the equipment from zapped by the over-voltage of the lightning strokes and works as a safety valve of the electrical system which operates only when surges or lightning strikes occur in the nature and diverts the excessive voltage to ground or limits the transient voltage, Based on the application and location called as surge or lightning arrester if located on the utility side of the meter, and are called as TVSS (Transient voltage surge suppressor) if located on the user side. It is used on the power supply panel boards if used on user side to protect the sensitive equipment's. Classified in to two types as **(1)** Crowbar device and **(2)** Voltage-clamping device.

B. MAGNETIC SYNTHESIZERS

Magnetic synthesizers used for the larger loads combining power-conditioning devices. Uses resonant circuit made of nonlinear inductor and capacitors to store energy, pulsating saturation transformers to modify the voltage waveform and the filters to filter out harmonic distortions. It supplies power through the zigzag transformers. Zig Zag transformers traps triplen harmonic current and prevents them from reaching the power source. Application incudes protection of large computer installation, computerized medical imaging equipment's, industrial processes like plastic extruders especially for voltage sags. This equipment protects from voltage sag transients, overvoltage, under voltage and voltage surge. It can be bulky and noisy. **[1]**

C. SMES (SUPERCONDUCTING MAGNETIC ENERGY STORAGE)

Superconducting magnetic energy storage is one of the advanced technologies used for storing electrical energy that are commercially available, even available in the form of milliseconds. It uses superconducting magnetic materials, which are even useful for elimination of losses in electrical equipment's. Circulating D.C current in the closed coil of superconducting wires creates magnetic field.

The path of the coil circulating current can be opened with the solid-state switch, which is modulated on and off (open). The magnetic coils will behaves as current source and will force current into the power converters, which will charge to some voltage level. Proper modulation of solid-state switch can hold the voltage within the proper operating range of the inverters, which converts the D.C voltage in to A.C voltage.

SMES system uses low temperature superconducting materials, which are cooled by the 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. **[1]**

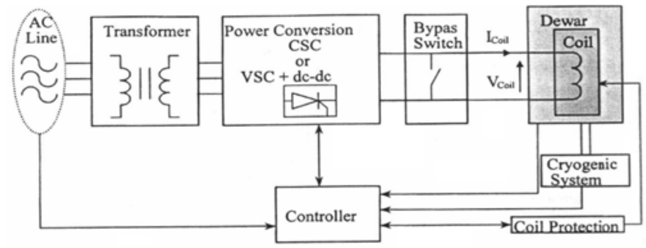


FIG-2: SMES SYSTEM

SMES systems are large and generally used for short durations, such as utility switching events.

D. HARMONIC FILTERS

Harmonic filters called the shock absorber of the electricity works on the principle that inductor and capacitor connected together will either block harmonic current frequencies or will provide a low impedance path flow to ground because an increase in frequencies increases the inductor impedance while reduces capacitor impudence. Utilities use harmonic filter on their distribution systems, while end users use harmonic filters in their facilities to keep harmonic currents from causing their electrical equipment to overheat and to detune resonating circuits.

The Harmonic filter classified such as: Active filter, Passive filter and newly developed Hybrid filter.

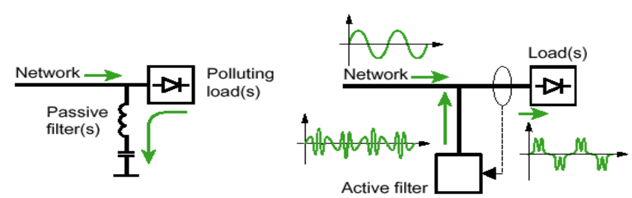


FIG-3: HARMONIC FILTERS

Passive filters **Fig. 3 (**left**)** consisting low impedance path to the frequencies of the harmonics to be attenuated using passive components (inductors, capacitors and resistors). Several passive filters connected in parallel may be necessary to eliminate several harmonic components. If the system varies (change of harmonic components), passive filters may become ineffective and cause resonance. Passive filters also have their classifications.

Active filters Fig. 3 (right) analyse the current consumed by the load and create a current that cancel the harmonic current generated by the loads. Active filters were expensive in the past, but they are now becoming cost effective compensating for unknown or changing harmonics. Alike Passive filter Active filter has also been sub-classified into different categories.

The Limitation of Passive and Active power filter was propagated by introducing hybrid power filter, which uses the construction of active and passive filters in combined system. This new filtering technology offering advantages of both active and passive filtering technique and covers a wide range of power. Hybrid filter can be shunt connected consisting an active filter connected in series with the passive filter having three phases PWM inverter. This filter effectively mitigates the problem of a passive and active filter. It provides cost effective harmonic compensation, particularly also for high power nonlinear load. **[1]**

VII. CONCLUSION

This paper presents different trending issues of modern society related with power system network. The modern society has to deal with problem like Voltage sag, Voltage swell, Interruptions, Harmonics, etc. while utilizing electrical power. The paper presenting an innovative technology management by critically analysing power quality problems, their related issues and while also presenting IEEE international standards on the limiting criteria encompassed with power quality problems, for safeguarding the electrical network and setting limits for the disturbance with their effect. Also stating few corrective measures, which can be helpful to the society for maintaining their safe operation of equipment. Power conditioning equipment's like Surge suppressor, SMES, Harmonic filtering technique, Magnetic synthesizer has been described. The corrective measures discussed can prove an ease of remedial measures for power quality problems generated in different equipment's and at different locations. Coordination with existing industry practices and international standards is also considered in paper. This can help research workers, users and suppliers of electrical power to gain a guideline about the power quality.

Thus it's an important area for design engineers and researchers to develop a power network that can perform satisfactorily without any disturbances.

VIII. FUTURE SCOPE

Soft computing techniques-Fuzzy logic controller based perfect harmonic cancellation technique (PHC) can be further used to reduce THD by 95 %(4.05 % for R-load and 3.84 % C motor load).

FACTS can also used as an improvised method for better system performance.

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