THE ISSUES OF POWER QUALITY IN POWER SYSTEMS, CORRECTIVE MEASURES AND STANDARD GRID CODES.

ABSTRACT

This paper reviewed the main problems/challenges of power quality in power systems at distribution ends. The causes, solutions, acceptable grid codes and network standards were presented. The power quality of the power system is affected by such issues as harmonics, voltage fluctuation and flickers, voltage sags and swells, long and short duration interruptions among others. These issues impact adversely on the performance of the power system causing malfunctioning power system equipment and components. Some of the effects includes, heating of metal parts of system equipments and transformer windings, noise in motors, flickering of lamps, false tripping of protective equipment and frequent outages e.t.c. All mentioned issues of power quality can be addressed by the use of appropriate mitigating techniques and correction devices.

Keywords: Power system, Power Quality, Harmonics, Voltage and frequency variation, voltage sag, flywheel

AUTHOR 1: EDAFE LUCKY OKOTIE (CORRESPONDING AUTHUR)

NATIONAL INSTITUTE OF CONSTRUCTION TECHNOLOGY, (NICT)

UROMI, EDO STATE. Email: l.okotie@nict.edu.ng, Mobile: 08038142707

AUTHUR 2: NICK OBINNA IHEDI-OKONKWO

DEPARTMENT OF COMPUTER ENGINEERING, UNIVERSITY OF BENIN

BENIN, EDO STATE.

1.0 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 [Yamini Arora, 2014]. However, in practice, power systems, especially the distribution systems, have numerous nonlinear loads, which significantly affect the quality of power supplies and 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 [M. Alan and M. Gain, 2012].

Power Quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems. Due to their non-linearity, all these loads cause disturbances in the voltage waveform.

1.1 POWER QUALITY PROBLEMS , AND CAUSES

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.

1.1.1 VOLTAGE SAG (OR DIP)

A decrease of the normal voltage level between10 and 90% of the nominal rms voltage at the power frequency, for durations of 0,5 cycle to 1 minute. Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors [A de Ameida et al, 2003].

Figure 1.0: Voltage Sag

1.1.2 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. Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off- peak hours).

1.1.3 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 multiples of power-system frequency. All non-linear loads, such as power electronics equipment including ASDs, switched mode power supplies, data processing equipment, high efficiency lighting.

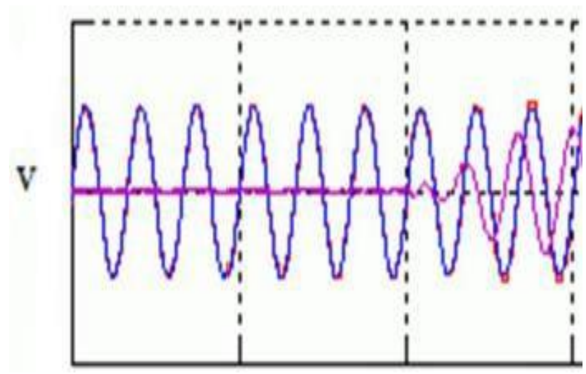


Figure 2: Harmonic distrotion

1.1.4 VOLTAGE FLUCTUATION AND FLICKERS

Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz. Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.

Figure 3: Voltage Fluctuation and Flickers

1.1.5 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. 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)

1.1.6 VERY SHORT INTERRUPTIONS

Total interruption of electrical supply for duration from few milliseconds to one or two seconds. Mainly due to the opening and automatic reclosure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.

Consequences of these interruptions are tripping of protection devices, loss of information and malfunction of data processing equipment [Langfang Li et al, 2014].

1.1.7 LONG INTERRUPTIONS

Long interruption of electrical supply for duration greater than 1 to 2 seconds. 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. A consequence of these interruptions is stoppage of all equipment [balasubramanian and prabha, 2015].

1.1.8. UNDER VOLTAGES

Excessive network loading, loss of generation, incorrectly set transformer taps and voltage regulator malfunctions, causes under voltage. Loads with a poor power factor or a general lack of reactive power support on a network also contribute. Under voltage can also indirectly lead to overloading problems as equipment takes anincreased current to maintain power output (e.g. motor loads) [seema jadhav, 2015].

1.1.9 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 [D. Sivakumar et al, 2016].

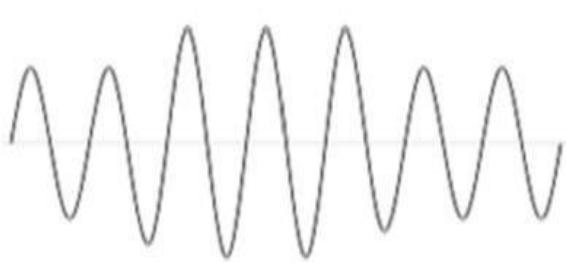


Figure 4: Voltage Spikes/rise

2.0 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 [P.Oshiebere, 2016].

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.

2.1 POWER QUALITY IMPROVEMENT MEASURES

Several types of power enhancement devices have been developed over the years to protect equipment from power disturbances. The following devices play a crucial role in developing an effective power quality strategy.

2.1.1 TRANSIENT VOLTAGE SURGE SUPPRESSORS (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. Employing an entire facility protection strategy will safeguard the electrical system against most transients. Multi-stage protection entails using TVSS at the service entrance, sub-panel a at the point of use. This co- ordination of devices provides the lowest possible let through voltage to the equipment. 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. TVSSs 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[Mehebub and Mandela, 2012].

2.1.2 HARMONIC FILTERS

Harmonic filters are used to reduce undesirable harmonics. They can be divided in two groups: passive filters and active filters. Passive filters consist in a 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. Active filters analyze 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 effectivecompensating for unknown or changing harmonics [A De. Ameida et al, 2003], [Balasubramanian and prabha, 2015].

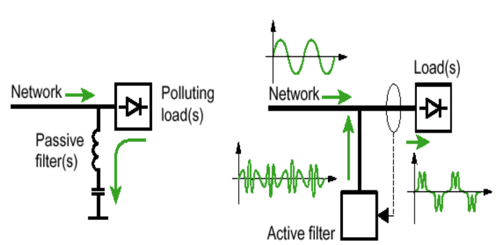
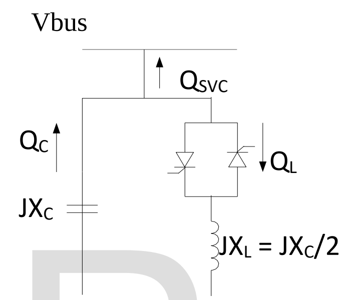


Figure 5: Harmonic filters.

2.1.3 STATIC VAR COMPENSATORS (SVCS)

Static VAR compensators (SVR) 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. The main application of SVR is the voltage regulation in high voltage and the elimination of flicker caused by large loads (such as induction furnaces). It is normally applied to transmission networks to counter voltage dips/surges during faults and enhance power transmission capacity on long [Langfang Li et al, 2014].



(a) A fixed capacitor with TCR (b) TCR and TSC with passive filter

Figure. 6: Structure of SVC

2.1.4 UNIFIED POWER QUALITY CONDITIONER (UPQC)

The unified power quality conditioner (UPQC) is a custom power device, which mitigates voltage and current-related PQ issues in the power distribution systems. The UPQC employs two voltage source inverters (VSIs) 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 [Seemar Jadhav, 2015].

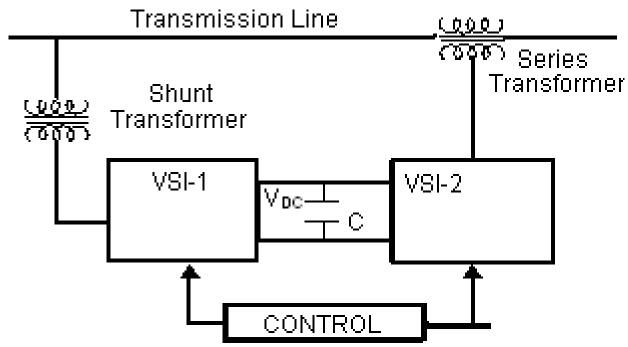


Figure 7: Basic Structure of UPQC [Alan and Gain, 2014].

2.1.5 ISOLATION TRANSFORMERS

Isolation transformers are used to isolate sensitive loads from transients and noise deriving from the mains. In some cases (Delta-Wye connection) isolation transformers keep harmonic currents generated by loads from getting upstream the transformer. 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. It provides a degree of isolation and filtering. These devices effectively reduce conducted electrical noise by physical separation of the primary and secondary through magnetic isolation. Isolation transformers reduce normal and common mode noises, however, they do not compensate for voltage fluctuations and power outages [Aruna, 2012]

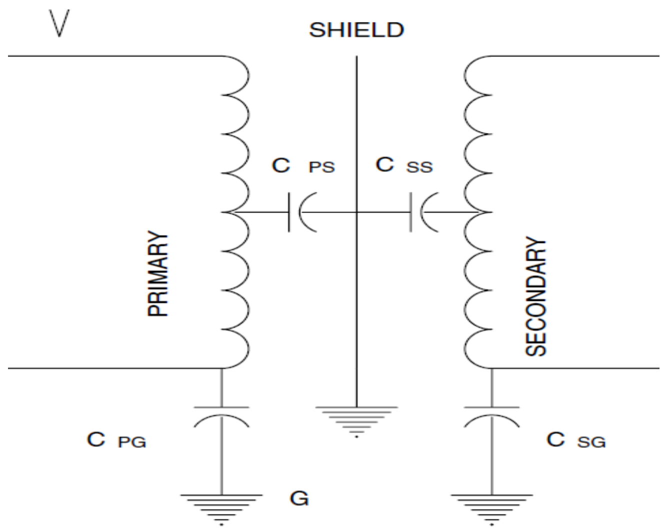


Figure 8: IsolationTransformer

2.1.6 UNINTERRUPTIBLE 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 [Ajabuego et al, 2017]. There are three major UPS topologies each providing different levels of protection.

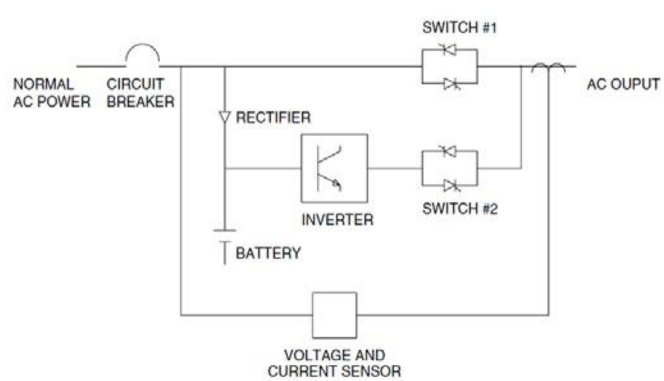


Figure 9: Offline UPS System

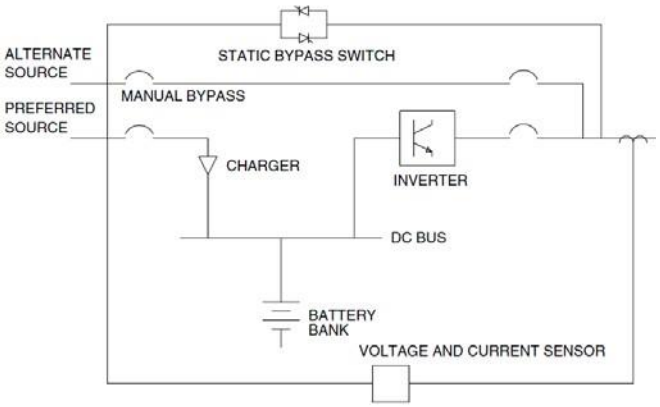


Figure 10: Online UPS system

2.1.7 GRID ADEQUACY

Many PQ problems have Original Source in the transmission or distribution grid. Thus, a proper transmission and distribution grid, with proper planning and maintenance, is essential to minimize the occurrence of PQ problems.

3.0 DISTRIBUTED RESOURCES- ENERGY STORAGE SYSTEMS

Interest in the use of distributed energy resources (DER) has increased substantially over the last few years because of their potential to provide increased reliability. These resources include distributed generation and energy storage systems. Energy storage systems, also known as restoring technologies, are used to provide the electric loads with ride-through capability in poor PQ environment. Recent technological advances in power electronics and storage technologies are turning the restoring technologies one of the premium solutions to mitigate PQ problems [Sivakumar et al, 2016].

The first energy storage technology used in the field of PQ, yet the most used today, is electrochemical battery. Although new technologies, such as flywheels, Super-capacitors and Superconducting Magnetic Energy Storage (SMES) present many advantages, electrochemical batteries still rule due to their low price and mature technology [Ajabuego et al, 2017], [Mehebub and Mandela, 2012].

3.1 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. Steel and are limited to a spin rate of a few thousand revolutions per minute (RPM). 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 to the square of the rotational speed. High speed flywheels can store much more energy than the conventional flywheels. The flywheel provides power during a period between the loss of utility supplied power and either the return of utility power or the start of a back- up power system (i.e., diesel generator). Flywheels typically provide 1-100.seconds of ride-through time, and back-up generators are able to get online within 5-20 seconds [Ajabuago et al, 2017].

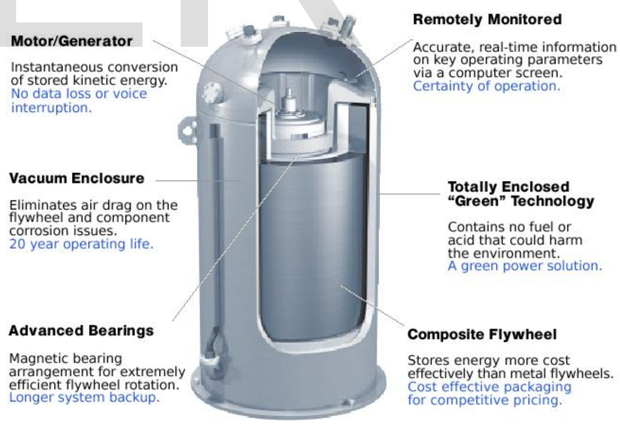


Figure 11: Flywheel[http://www.beaconpower.com]

3.2 SUPERCAPACITORS

Supercapacitors (also known as ultracapacitors) 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 supercapacitor provides power during short duration interruptions or voltage sags. Medium size super capacitors (1MJoule) 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.

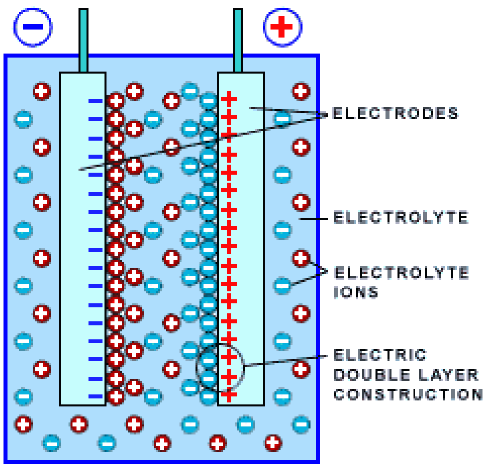


Figure 12: Electric double layer supercapacitor

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 [10-11].

4.0 CODES AND STANDARDS

Some measures have been taken to regulate the minimum PQ level that utilities have to provide to consumers and the immunity level that equipment should have to operate properly when the power supplied is within the standards. Standardization organizations like IEC, CENELEC, and IEEE have developed a set of standards with the same purposes [[Balasubramanian and prabha, 2015].]. Nonetheless, the IEEE standards give more practical and some theoretical background on the phenomena, which makes it a very useful reference. Some of the IEEE power quality standards are described in the ensuing sections.

4.1 IEEE 519

Power system problems that were associated with harmonics began to be of general concern in the 1970s, when two independent developments took place. Industrial consumers and utilities began to apply power factor improvement capacitors. The move to power factor improvement resulted in a significant increase in the number of capacitors connected to power systems. American standards regarding harmonics have been laid out by the IEEE in the 519 Standard: IEEE Recommended Practices and Requirements for Harmonic Control in Electric Power Systems. There is a combined effect of all nonlinear loads on utility systems that have a limited capability to absorb harmonic current.

Further, utilities are charged with the responsibility to provide a high quality supply in terms of voltage level and waveform. IEEE 519 recognizes not only the absolute level of harmonics produced by an individual source but also their size relative to the supply network. It should be noted that IEEE 519 is limited to being a collection of Recommended Practices that serve as a guide to both suppliers and consumers of electrical energy.[Balasubramanian and prabha, 2015].

4.1.1 IEEE STANDARDS RELATED TO VOLTAGE SAG AND RELIABILITY

The distribution voltage quality standard i.e. IEEEStandard P1564 gives the recommended indices and procedures for characterizing voltage sag performance and comparing performance across different systems. Anew 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.

4.1.2 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.

4.1.3 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.

4.1.4 STANDARDS RELATED TO DISTRIBUTED GENERATION

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

5.0 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 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. This paper gives a comprehensive review by critical analyzing about power quality problems, issues, related international standards, and the solutions. The correct solutions are also discussed which can be remedy for power quality problems generated in different phenomena. To avoid the huge losses related to PQ problems, the most demanding consumers must take action to preventthe problems. Among the various measures, selection of less sensitive equipment can play an important role. 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.Apower quality audit can help determine the causes of your problems and provide a well-designed plan to correct them. The power quality audit checks the facility's wiring and grounding to ensure that it is adequate for your applications and up to code.

REFERENCES

A. de Ameida, L. Moreira, J. Delgado, 2003: Power quality problems and new solutions. ISR-Department of Electrical and Computer Engineering, University of Coimbra, Polo II, 3030-290 Coimbra (Portugal)

Aruna Garipelly, 2012: Improvement of Power quality of a distributed generation power system. International journal of advances in engineering and technology, ISSN: 2231-1963

D. Sivakumar, J.P. Srividhya and T. Shanmathi, 2016: A review on Power quality monitoring and its controlling techniques. 8th international conference on latest trends in engineering and technology, May 5-6,2016 Dubai (UAE)

Lanfang Li, Ming Ma, Baiya Xu, Zhengfu Liu, Yuan Li and Honggeng yang, 2014: Power quality of distributed networks with high penetrated intermittent distributed generation. A survey. International conference of power system technology

Mehebub Alan, Mandela Gain, 2012: Power quality problems and solutions: An overview, International journal of science and research ISSN: 2319-7064

O.G. Ajabuego, E.C.N. Okafor, F. Izuegbunam and M. Olubiwe, 2017: Impact of distributed generation on the power quality of power supply in Nigeria; Port Harcourt Network Case study. International Journal of Engineering research and technology. ISSN: 2278-0181, pp. 507-510

P.M. Balasubramanian and S.U. Prabha, 2015: Power quality issues, solutions and standards: A technology review, Journal of applied science and engineering, Vol. 18, No. 4, pp 371-33

Patrick Oshiovbere, 2016 : Impact of DG on power quality of the Nigerian power system, A case study of Otovwodo 15MVA, 33/11kv injection substation, Otovwodo, delta state, Nigeria, A thesis submitted to

ISSN 2229-5518

Department of Electrical Engineering University of Benin.

Seema Jadhav and Ruchi Harchandani 2015: Grid interfacing technologies for distributed generation and power quality issues-A Review., International journal of innovative and emerging research in enginerring. E-ISSN: 2394-3343, P-ISSN: 2394-5494, Vol.2, Issue 3, pp. 233-237

Yamini Arora 2014: A Review on power quality problems and its solution at distribution end using different interfacing devices and distributed resources. International journal of emerging trends in engineering and development, Issue 4, vol.5, ISSN: 2249-6149