ELECTRICAL NETWORK POWER QUALITY ISSUES, CUASES, CONSEQUENCIES AND TECHNICAL MITIGATING METHODS

Abstract

Electrical power or energy must not just be available; it must also meet standard supply conditions for safe and effective consumption. The nature of supply voltage at anytime is very vital for smooth operation and prolonged service-life of equipment. The quality of the power supply is thus determined by the system voltage characteristics. The degree to which the supply voltage conforms to the acceptable standard is referred to as Power Quality. Nowadays, with the increasing use of power electronic devices in domestic and commercial environment as well as sensitive equipment in the industries for automated operation of production facilities, it has become very necessary to continually maintain the power quality of the power system. The Power Quality as well as issues associated with it. The causes and consequences of power quality problems are presented and possible mitigating techniques to relax the power quality issues were suggested.

Keywords: Power Quality, Voltage Quality, Current Quality, Overvoltage, Voltage Sag, Voltage Swell, Mitigating Techniques, Power Quality Standard

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1. Introduction

The quality of power supply is very important in any power network to both electricity consumers and utility network owners. Power quality covers availability of power supply, voltage and frequency magnitude as well as nature of the waveform of the power supply. Power is described to be of good quality if the electricity supply is constant at acceptable, steady values of voltage and frequency, and has smooth sinusoidal waveform (Daniel et al, 2016). However, in practice, varying electricity demands, certain equipment (at home, office and industry) and faults cause disturbances on the power system, thereby causing it to deviate from standard characteristics.

Power quality is said to be poor when at least one of these occurs

- the supply is not constant (outage or interruption or fluctuation),
- when the supplied voltage is lower to or above acceptable range of magnitude,

- when the power system frequency is fluctuating.
- and when the current and voltage sinusoidal waveform of the supply is distorted.

Power quality therefore, can be defined as the extent of deviation from nominal values of frequency, current and voltage magnitude (Yamini, 2014). The deviation can also be in term of shape of waveform. Power Quality may also be explained to be the degree to which the supplied power is compatible with the smooth operation of electrical equipment. In other words, it is a measure of how well a power system supports smooth operation of its loads. From a customer perspective, Power Quality problem is any power problem manifested in voltage, current, or frequency deviations which result in power failure or misoperation of customers' equipment (M. Alan and M. Gain, 2012)

Poor power quality is a serious problem for domestic, commercial and industrial consumers. For instance, some appliances and gadget at domestic level may not work properly if the voltage is below or above acceptable value which may even damage the appliance. Poor power quality may cause bulb and electrical equipment to malfunction or not operate at all and which eventually leads to early failure. In industries, low power quality is problematic for increasingly automated sensitive production machineries.

There has been steady increase of power quality research and publications in the last two decades as result of significant concern and increase of power quality problems mostly caused by proliferation of electronics equipment such as power electronic, energy-efficient lighting, information technology equipment etc. Most of the publications detail some causes and mitigation techniques of poor power quality. In this paper, in addition to presentations of more causes and its effect, emphasis is placed on power quality monitoring and in design stage of electrical systems and equipment. Power quality challenges can be drastically reduced if equipment and power systems are designed to cope well with it.

Power Quality issues surface in electric equipment, electric arc furnace, aircraft electrical system, railway systems, renewable energy, electric motors, industrial processes, in power transmission and distribution systems; and in many other electric power systems applications. Power Quality involves areas of voltage variations, frequency fluctuations, transient, harmonics, current and voltage unbalance etc. (Balasubramanian et al, 2015)

1.1. 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.

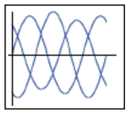

Figure 1: Voltage Unbalance

Causes:

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).

Consequences:

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 machines.

1.2. Voltage Sag (or Dip)

A decrease of the normal voltage level between 10 and 90% of the nominal rms voltage at the power frequency, for durations of 0,5 cycle to 1 minute. (De Ameida et al, 2016)

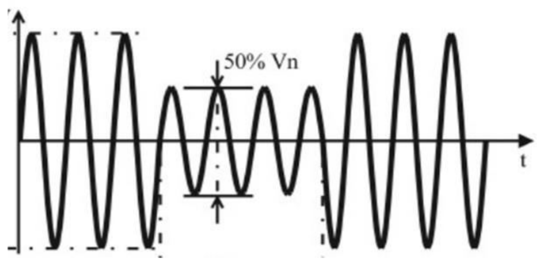

Figure 2: Voltage Sag

Causes:

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.

Consequences:

Malfunction of 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 and loss of efficiency in electric rotating machines (Almeida et al, 2016).

1.3. Voltage Swell

Voltage swell is the opposite of voltage sag which is momentary increase in nominal supply voltage. Voltage swell is rise to within 1.1 to 1.8 pu of the normal voltage for duration from half a cycle to several seconds (). It occurs when heavy load is turned off, loss of generation, badly regulated transformer, faulty conditions at various points in the AC distribution system, under-loading of a phase while other two phases in a 3-phase system are overloaded. Figure 2 shows the waveform of voltage swell.

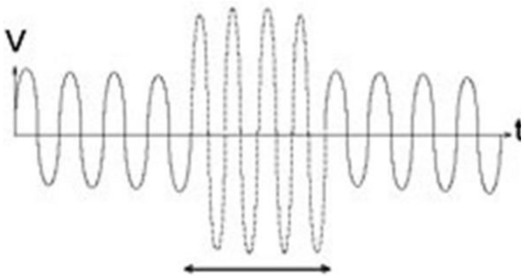

Figure 3. Voltage swell.

Causes:

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

Consequences:

Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.

1.4. Voltage Fluctuation and Flickers.

Voltage fluctuation is the oscillation of voltage values, amplitude modulated by a signal with frequency of 0 to 30Hz. It is a series of voltage changes on a cyclical variation of the voltage envelop which change in the range of 0.01% to 7% [IEEE std. 1159, 2009].

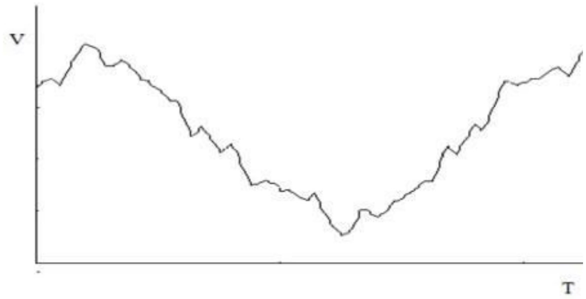

Figure 4: Voltage Fluctuation and Flicker

Causes

- Voltage variation occur due to variation is solar irradiance caused by the movement of cloud and may continue for minutes or hours depending in the intended area covered by the PV system and the topology of solar radiation used.

Consequencies

- Over and under voltage
- Flickering of light giving impression of unsteady of visual perception
- Power saving in lines (Ameida et al, 2016).

1.5. Interruption

Power interruption occurs when the supply line voltage reduces to less than 0.1 pu for a period not longer than 60 seconds. It becomes sustained interrupti6on if it is longer than one minutes.

Causes include insulation failure, improper/faulty grounding, and lightning and insulator flashover. It results in opening and automatic re-closure of protection devices to isolate faulty section of the system. Figure 3 gives illustrates interruption.

1.5.1. Very Short Interruption

Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

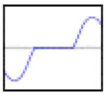

Figure5: Short Interriuption

Causes:

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:

Tripping of protection devices, loss of information and malfunction of data processing equipment. Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal with this situation.

1.5.2. Long Interruption

Total interruption of electrical supply for duration greater than 1 to 2 seconds (De Ameida et al, 2016)

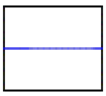

Figure 6: Long interruption

Causes:

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.

Consequences: Stoppage of all equipment

1.6. Voltage Spikes

Very fast variation of the voltage value for durations from a several microseconds to few milliseconds. These variations may reach thousands of volts, even in low voltage.

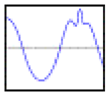

Figure 7: Voltage Spikes

Causes:

Lightning, switching of lines or power factor correction capacitors, disconnection of heavy loads.

Consequences:

Destruction of components (particularly electronic components) and of insulation materials, data processing errors or data loss, electromagnetic interference.

1.7. Noise

Superimposing of high frequency signals on the waveform of the power-system frequency.

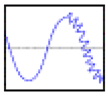

Figure 8: Noise

Causes:

Electromagnetic interferences provoked by Hertzian waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.

Consequences:

Disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors.

1.8. 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 (Fehr, 2016.).

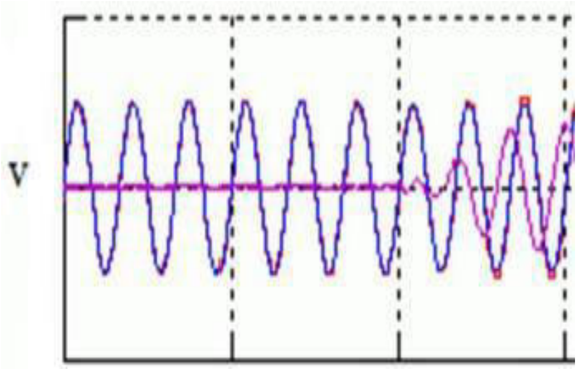

Figure 9: Harmonic Distortion

Causes:

Classic sources: 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.

Consequences:

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.

1.9. Inrush Current

The inrush current is the maximum instantaneous input current drawn by a power supply or electrical equipment at start-up or turn-on. This current can be as high as 20 times the steady state current but last for a short period of about 10ms and takes about 30 to 40 angles to stabilize to normal operating values (Lanfang et al, 2015)

Causes

- The small inevitable difference between PV systems and grid voltages may introduce an inrush current that flows between the PV system and the utility grid at connection time but decays to zero at an exponential rate (yamini , 2014).

Consequencies

- Nuisance tripping of production equipment and protective devices
- Thermal stress on transformer windings
- Damage to power sensitive equipment

1.10. Frequency Fluctuation

The electric power network is designed to operate at a specified frequency value (50Hz) as in the case of the Nigerian power system [Yamini, 2014].

Causes

- The unbalance between the power supplied and consumed especially in distribution system with high PV penetration (Khalid et al, 2011)

Consequencies

- Change in the winding speed of electric motors
- Damage to generators

1.11. Others Power Quality Issues Includes

1.11.1 Overvoltage

Overvoltage is an increase in nominal rms voltage greater than 1.1 pu for duration longer than one minute. It result from switching off of large load, incorrect tap setting of transformers, inadequate voltage control, fault on the line.

Causes and Consequences is the same as that of Voltage dip

1.11.2 Undervoltage

Undervoltage is decrease in nominal voltage to less than 0.9 pu for longer than one minute duration causes includes switching on of large load, circuit overloading, fault on the line.

Causes and Consequences is the same as that of Voltage spikes

2.0. Regulating Standards on Power Quality

There are quite a number of professional standard organisations for power quality while many are national body, few are transnational. The most widely accepted standards are International Electrotechnical Commission IEC and Institute of Electrical and Electronics Engineer IEEE. These standard organisations provides the minimum benchmark required, acceptable technical practice and gives recommendation on electrical and electronic technical issues. Some of the international standard codes are presented bellow.

2.1 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.

2.1.1 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.

2.1.2 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.

2.1.3 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.

2.1.4 STANDARDS Related to Distributed Generation

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

3.0. Power Quality Monitoring

Power Quality Monitoring (PQM) is the process of gathering, analysing and interpreting raw power measurement data into useful information (Ahmed et al, 2015). It involve, over a period of time, process of measuring voltage and current of the supply and examining their waveform, although the analysis is not limited to these two quantities. It includes inspection of wiring, grounding, equipment connections. The monitoring of power supply helps to detect present and potential power quality problems that may gradually shortens the life span of equipment. PQ monitoring help to improve facilities' power quality performance. Power utilities are to ensure that the quality of power supplied is within specified and acceptable standards and be ever ready to normalise any technical issues that affect the quality of power delivered. The latest advances in electronic and communication technologies offers opportunities for monitoring large and complex power systems in an efficient manner. Utilities can take this advantage to collect data on different part of power networks, assess the performance of the system and respond accordingly as well as address complains from the power consumers (More 2014).

Good power monitoring instrument provides useful information and reliable analysis about power quality. Examples includes:

- In-plant power monitor which gives the voltage profile and wave shape of the supply for voltage sag, swell, voltage variation and harmonic level evaluation.
- Digital Fault Recorder DFR, triggers on fault event and records current, voltage and their waveform at the time of the fault for analysis.
- Disturbance Analyser can measure wide variety of power disturbance from a very short duration transient voltage to long duration undervoltages and outages

3.1. Flicker Meter

Flicker Meter is a measuring device to evaluate the level of voltage flicker annoyance. The flicker meter is a special analyzer modelling response of a chain consisting of reference 60W incandescent lamp-eye-brain of an average observer. It has two main part, the first part attempt to simulate the behaviour of the set lamp-eye-brain and the second part focus on statistical analysis of the instantaneous flicker perception (Deepak et al, 2016)

Circuit Monitor provides accurate, reliable and fast alarm detection and multiple levels of information on each power quality issue to help identify the source and cause of a problem including harmonic power flows, flickering, sag, swell.

3.2. Oscilloscope

Oscilloscope measure voltage and current and can display harmonics present in all power quality events.

3.3. Power Quality Meter and Analyser

Power Quality Meter and Analyser is an instrument similar to oscilloscope but more suitable and more versatile for power quality monitoring. It can measures frequency, voltage, current, phase rotation, apparent and real power, harmonics and can also record and store the measured data and analyse them with PC-software.

4.0. Mitigation Techniques

There are numbers of measures to ensure good power quality delivery. Mitigation of power quality problem may take place at different level of power system: at power plant, at transmission lines and stations, at primary and secondary distribution networks as well as at the service equipment and customers' building wiring. It should be noted that the problem of power quality cannot be eliminated completely except some equipment can be done away or if lightning strike can be prevented or if fault can be eliminated. However effect of power quality problem can be drastically reduced to almost zero.

Mitigation of PQ problems may take place at different levels

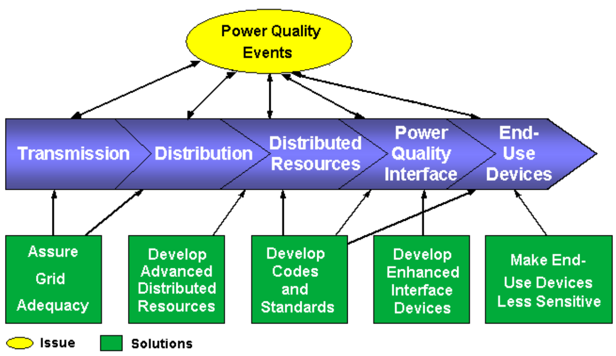

Figure 10: Mitigation of PQ issues

4.1. Availability/Grid Adequacy

Ensuring there is adequate power in the grid. Adequacy of the grid is the capacity of the power plant and transmission lines to meet up with the load demand and energy need of the customers. It relates to the sufficient generation, transmission and distribution infrastructure within the system to satisfy customer electric demand (Ameida et al, 2016). This is necessary to minimise power quality problems.

4.2. Design of Equipment

Equipment manufacturer should be well aware of power quality issues and design equipment in such a way that the equipment itself does not contributes to power quality problems. Also the equipment should be design to withstand and be less sensitive to disturbances in the power systems. This will help in reducing effect of power quality problems.

4.3. Mitigating Equipment/Enhanced Interfacing Devices

There are numbers of power electronic devices that can be employed to interface between the supply socket and sensitive equipment. This is to prevent power quality problem in the supply from reaching the equipment. An example is the use of automatic voltage regulator AVR to maintain constant voltage into sensitive equipment in spite of any voltage sag, swell and any form of under or overvoltage. Another example is UPS which maintains supply to equipment when there is momentary power interruption. Another one is Dynamic Voltage Restorer DVR which restore smooth sinusoidal line voltage even if the source voltage waveform is degraded or distorted. DVR is voltage source converter. DVR is usually use to interface between the power source and sensitive load to be protected.

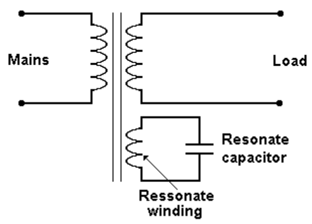

Figure 11: Constant voltage transformer

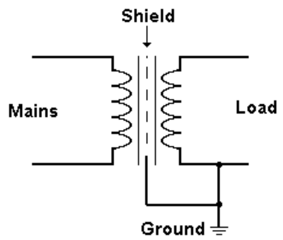

Figure 12: Isolation transformer.

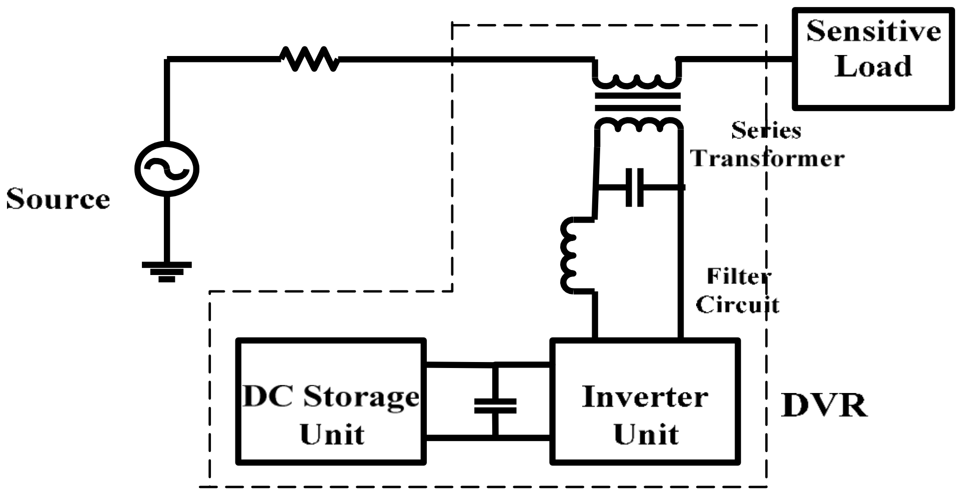

Figure 13: DVR Structure [Sandeep, 20014]

4.4. Filter

Filter are used to permit the flow of wanted frequency and block unwanted signal from getting to the protected equipment. Filter is constructed with capacitors inductor and resistor that create low impedance path for the wanted fundamental frequency and high impedance path for the frequency intended for elimination. Harmonic filter cancel harmonics produced by nonlinear load by injecting an exact complimentary harmonic current to it. Different filters types include active harmonic filters, passive harmonic filters, line-reactors, electronic feedback filters and special transformers that use out of phase windings to accomplish harmonic reduction (Deepak et al 2016)

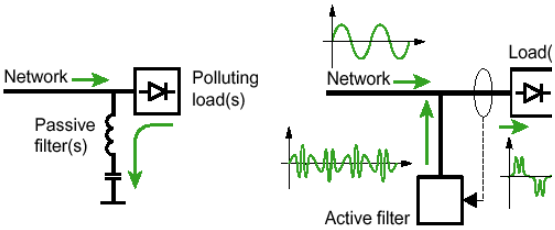

Figure 14:
Harmonic filters.

4.5. Proper Grounding of Electrical System

Proper grounding of electrical system does not only protect installation, equipment and users but also play a key role in enhancing better performance of the system. Poor earthing is one of the causes of poor power quality, particularly at the consumers end.

4.6 Make End-use Devices Less Sensitive

Designing the equipment to be less sensitive to disturbances is usually the most cost effective measure to prevent PQ problems. Some manufacturers of end-use equipment are now recognising this problem, but the competitive market means that manufacturers should reduce costs and only respond to customers' requirements. The exception is the ASD market, where manufacturers are actively promoting products with enhanced ride-through capabilities.

Adding a capacitor with a larger capacity to power supplies, using cables with larger neutral conductors, derating transformers and adjusting undervoltage relays, are measures that could be taken by manufacturers to reduce the sensitivity of equipment to PQ problems.

5.0. Conclusion

This paper has reviewed what power quality is. It outlined the causes of power quality problems, their consequencies in power system and suggested ways to mitigate them. The effect of power quality problems include inefficiency, overheating and shortening service-life of equipment, loss of data, process interrupt, insulation breakdown. Yes it may not bre possible to completely eliminate the causes but then, the quality of power supply can be improved and the effects in the supply system can be minimized. The mitigating techniques are adequate energy availability in the grid, use of enhanced interfacing devices (UPS, AVR, DVR, SVC, etc.), use of power quality improving devices (tap changing transformer, lightning arrestor, VAR, UPQC), use of filter to block harmonics, as well as proper grounding of electrical installations and making end user equipment less sensitive to PQ issues with proper equipment designs..

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