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Power Quality Indices and Mitigation Techniques: A Review

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Abstract

It is obvious that the power generation in Nigeria cannot meet the power demand of the growing population due to inadequate planning. This shortage in power generation has culminated into poverty, underdevelopment and poor standard of living in the country. The existing network design was structured in such a way that power quality at the consumer level is extremely poor. The issues with power quality and the causes of power quality problems are discussed. Voltage sag was extensively reviewed in this paper. The four characteristics of voltage sag are thoroughly examined ranging from magnitude, duration, unbalance of sag to phase angle jump. The paper also reviewed voltage sag estimation which includes: singular value decomposition technique, voltage sag source location, simple regression and multiple regression. Mitigation techniques are also discussed such as constancy of power supply, Dynamic voltage restorer, filters, static var compensator, energy storage system, flexible alternating current transmission systems and transformers. International best practice which is in accordance with IEEE regulations should be implemented on the networks for good power quality.

Keywords: *power, mitigation, quality, deterioration, reliability.*

Introduction

The components of power system network design are characterized by faults which has grievous effects such as reliability deterioration and inevitability of supply; sensitive electrical industrial appliances are destroyed; loss of revenue; security threats and loss of lives in the hospitals. Generator faults include: exciters instability due sudden increase in load and armature reaction; total field loss and for transmission and distribution systems, degradation of insulation; damage due to natural effects; sudden switching of other disturbances; damage due to natural effects sudden switching or other disturbance and collapse of insulation [1]. Electrical energy produced from energy centers are conveyed over a long transmission lines along vegetations through poles to the load centers where distribution to end users take place. Factors that negate conveyance of energy to load centers are losses, line characteristics, transmission capabilities, inadequate funding, human beings etc. have hampered adequate power delivery[2].Power quality (PQ) could be any product or service that is provided to users or utilities to measure, treat, correct,educate engineers or prevent power quality issues, problems and related items[3]. PQ problem is any problem manifested in voltage, current or frequency deviation which leads to mis-operation of equipment or lack of power supply[4]. Voltage quality problems were obviously in existence particularly before 1980. Households used electricity exclusively for lighting and the supply was through long low voltage lines which make voltage at the consumers end very low. However, modern appliances require quality power. To improve PQ medium voltage substations and power houses are expected to be installed closer to households [5]. PQ is poor when the supply is not constant; when the supplied voltage is not within the acceptable limits; when the power system frequency is fluctuating and when the current and voltage sinusoidal waveform of the supply is distorted [6].

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The issues with power quality are:

1. Under-voltage: It is a decrease in nominal voltage followed by a voltage recovery after a long period of time. The causes of under-voltages are malfunctioning of voltage regulators; excessive network loading; loss of generation; and wrong transformer taps [7].
2. Voltage sag: It is a sudden reduction of voltage in the electrical system followed by a voltage recovery after a short period of time from half cycle to a few seconds. It is the decrease of rms value of voltage from 0.1 to 0.9 per unit for duration of 0.5 cycle to 1 minute[8], [9]. It causes serious problems to sensitive load and facilities due to expensive outages leading to unbearable economic losses[7], [10], [11].
3. Voltage spike: It is a fast variation to the voltage level for duration from a several microseconds to few milliseconds. It is caused by lightning, switching of lines or power factor correction capacitors and disconnection of heavy loads. It may be associated with destruction of components and insulation materials, data processing errors or loss of data and electromagnetic interference[12].
4. Voltage swell: It is the opposite of voltage sag which is momentary increase in nominal supply voltage. It rises within 1.1 to 1.8 per unit of the nominal voltage for a duration of half cycle to severalseconds[6].
5. Flicker: It is caused by switching on and off of electric motor pulsating load, arc furnaces and welding equipment. It causes irritation to human sight. It is as a result of rapid changes in brightening and dimming of screen and variation in luminosity produced by electric bulb. It is due to the effect of repetitive and random variations in voltage between 0.9 and 1.1 per unit [6].
6. Frequency variation: Frequency variations that are not within tolerable value of ±5% is not healthy for power system thereby leading to system collapse. They are encountered in small isolated networks due to faulty or maladjusted governors; overloading of the network. However in an interconnected grid system, a failure in governor will not create any disturbance in the system[6], [7].
7. Overvoltage: It is an increase in nominal r.m.s voltage greater that 1.1 put for a duration longer thatone minute. This usually results into incorrect tap setting of transformer, inadequate voltage control, faulty lines and switching off of large loads[6].
8. Interruptions: It depends on the duration which is classified into instantaneous; momentary, temporary and sustained types. They can cause disruption, damage and downtime from house user up to industrial user. The causes of interruptions are loss of supply; tree contacts lightning; adverse weather, foreign interference and defective equipment [13],[14], [15].
9. Harmonics: These are sinusoidal voltages or currents that have frequencies, whose values are whole multiples of the frequency for which the supply systems are designed to operate i.e 50Hz or 60 Hz. The causes of harmonics generation are the non-linear loads. Non linear loads do change its impedance with instantaneous applied voltage that will lead to a non-sinusoidal current drawn when the applied voltage is low. Linear load draws instantaneous proportional current to the applied voltage while its impedance is constant along the alternating period. The effects of harmonics are high fault current; distribution system impedance and distortion is low; harmonic current drawn is low. Its effect are conspicuous on generators, transformers, induction motors, cables, lightning circuit breakers and fuses[16],[17],[18].

Voltage Sag Estimation

Voltage sag estimation(VSE) is defined as the task on estimating the voltage sags number at unmetered bus-bars by using the collecting data at a limited number of meters installed in the network. The methods used are realizing stochastic prediction and the conventional state estimation where measurements and simulations are used simultaneously. A probabilistic method can be used to obtain most probable voltage sag index at unmetered bus-bars given a measurement set as mentioned [19]. Other authors noted that the use of statistical modeling to analyze the effects of faults on networks is of great importance[20,21]. The results of the approaches are sensitive to high variability of fault statistical data and the inaccuracy of voltage sag number is experienced.

VSE problem is formulated asundetermined linear systembased on fault position concept [22]. Singular Value Decomposition technique (SVD) allows researchers to estimatethe number of voltage sag in unmetered bus-bars. SVD method is based on the least square and gets a solution with minimum norm. This method obtains a state vector with many non-zero values. ρ-norm minimization method solves an undetermined linear problem while the optimal vector is sparse[23].

Voltage sag source location methods have been developed for determining the source of voltage sag from single monitoring bus given a directional result which is upstream or downstream. Voltage sag source are identified by sampling voltage and current waveforms. The recorded pre sag and sag events, the integral of the disturbance power was obtained to identify the voltage sag source location. The sag source is said to be located downstream from monitor location if the final disturbance energy is positive and it is termed upstream when the final disturbance energy is negative. Another method based on the real current component was developed for voltage sag source location$(I\cos\theta)$. This requires calculation of power factor angle using both recorded current and voltage waveforms.

When there is one independent variable it is called as a simple regression but when there are more than one independent variable it is called as multiple regression or sometime multivariable regression. It is a statistical technique used in applied sciences. Multiple regression finds a set of partial regression coefficients, B such that the dependent variable, Y can be approximated by a linear combination of the 'K' independent variables, X. A predicted value, denoted by Y dependent variables is obtained as

$Y = B_0 + B_1x_1 + B_2x_2 + \cdots + B_kx_k + \in$ ……………(1)

Where B_j , (0,1,2,…K) are unknown quantities of regression coefficients and ∈ is a random error

For n number observations, equation 1 can be written in matrix form as:

$Y = X * B + e$…………………. (2)

Where $Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix}, X = \begin{bmatrix} X_{11} & X_{12} & \vdots & X_{1k} \\ X_{21} & X_{22} & \vdots & X_{2k} \\ X_{31} & X_{32} & \vdots & X_{3k} \end{bmatrix}, B = \begin{bmatrix} B_0 \\ B_1 \\ \vdots \\ B_k \end{bmatrix}, \rho = \begin{bmatrix} \rho_1 \\ \rho_2 \\ \vdots \\ \rho_k \end{bmatrix}$

Voltage deviation, $VD = \Delta V = V_{norm} - V_{sag}$

Standard Deviation S.D $= S = \sqrt{\frac{\sum_{i=1}^{n}(V_i - \bar{V})^2}{n-1}}$

Characteristics of voltage sag

a. Magnitude:The sag magnitude is the minimum of r.m.s voltage and refers to the retained voltage or todrop of the voltage. A 70% sag in a system of 230V indicates that the voltage dropped to 161V. The use of r.m.s voltage is the approach used in obtaining the voltage sag magnitude. R.M.S voltage of fundamental component and peak voltage could be used as an alternative.

$$V_{r.m.s}(K) = \sqrt{\frac{1}{N}\sum_{t=K-N+1}^{k} V_i^2}$$

b. Duration: the duration of a sag is commonly determined by the speed of the fault clearing time. Voltage sag duration is the period of time in which the voltage is lower than the stated limit; normally, sag duration is less than 1 second which is categorized into three, namely:
    1. Instantaneous (0.5-30 cycles)
    2. Momentarily (30 cycles-3s)
    3. Temporary (3s-1min)

c. Unbalance of Sag: Faults are classified into symmetrical and asymmetrical depending on the type of fault. In three phase, sag is symmetrical while in single phase, double phase or double line to ground faults the sag in three phase is asymmetrical.

d. Phase angle Jump: short circuit is one of the causes of voltage sagin power system. Changing of phase angle of voltage leading to phase angle jump. It is visible in a time domain plot of the sag as a shift in voltage zero-crossing between the re-event and the event itself.

Mitigation techniques:

In order to eliminate power quality problems, non linear loads and lightning strike should be prevented if possible. The effect of power quality problems can be reduced. The following mitigation techniques are recommended.

1. Constant power supply: Power supply should be constant, adequate and reliable. The power generated, transmitted and distributed should satisfy the demand of electricity consumers [6][24].
2. Implementation of available power electronic devices: They are employed between the supply socket and sensitive equipment. This prevents transfer of power quality problem from the supply to the equipment. Automatic Voltage Regulator maintains constant voltage into sensitive equipment in spite of voltage sag, swell, under or over voltage. An uninterruptible power supply maintains supply equipment when there is momentary power interruption. Dynamic voltage restorer restores smooth sinusoidal line voltage even if the source voltage waveform is degraded or distorted. It is usually used to interface between the source of supply and sensitive load [6].
3. Filters: Filters are classified into passive harmonic filters and active harmonic filters. The passive type is composed of inductors and capacitors tuned to cancel or trap a certain harmonic frequency usually of low order. Active types are power electronic equipments used to cancel current harmonic pollution of an installation[18].
4. Static var compensators is a shunt connected assembly of capacitors and possibly reactors which provides reactive power to a network during disturbances to minimize distortions[7].
5. Thyristor based static switch: It is a versatile device for switching a new element into the circuit when voltage support is needed. This device is used to correct voltage spikes, sag or interruptions. The static switch is used to switch in one of the following capacitor, filter, alternative powerline or energy storage system. It protects against 85% of the interruptions and voltage sags[7].
6. Energy storage system: These are employed to shield sensitive production equipment from shutting down caused by momentary interruptions or voltage sags [7]Flexible ac transmission system: It can be used for improving the power quality at the point of connection with the power network [25].
7. Transformers: They can form part of active front ends which have the ability to cancel load harmonics. They do discriminate certain harmonics to circulate upstream in the installation rather than eliminate them. These transformers are delta star;zigzag and delta-star-delta transformers [18]

Conclusion

This paper has extensively reviewed the power quality indices and the mitigation techniques. The causes of power quality problems ranging from non constant power supply, voltage operating outside the acceptable limits; power system frequency is fluctuating and distortion of current and voltage sinusoidal waveform. Mitigation techniques such as constant power supply, implementation of available power electronic devices, filters static var compensators, thyristors based static switch, energy storage system, flexible ac transmission system and transformers. The power quality indices were thoroughly expatiated ranging from undervoltage, voltage sag, voltage spikes, voltage swell, flickers, frequency variation, overvoltage interruptions and harmonics.

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