Total Power Quality Concept in Electricity Distribution Networks

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ABSTRACT
For sustainable electrical power network, the existing legal and policy framework on power quality in many distribution networks are rather too weak to address the problem bedeviling the power sector in many countries especially in the developing worlds. While the main focus on electricity industries globally has shifted from reliability to power quality; it is not so in many developing countries where reliability is still major challenges and utility is viewed as sole contributor of power problems. Hence, with the increasing power electronic non-linear loads devices serving as solution on one hand and causing disturbances in the network on the other hand, there is need to address the power quality alongside with the reliability in line with the emerging trend. This paper proposes that total power qualities consisting of Supply quality which is made of voltage and service qualities and utilisation quality made of current and response qualities are proposed to cater for the emerging trend. These terms are further classified as technical quality and non-technical qualities to further reflect and capture vividly the concept of total power quality concept for comprehensive power quality solutions that encompasses quantity and quality, technical and non-technical services in electricity distribution network. It defines Total Power Quality concept as a combination of supply quality and utilisation quality. Various definitions of terms associated with it are further proposed to reflect the emerging trend in the power sector. This concept will be useful in power system planning especially in developing countries.

Keywords: Total Power Quality, Reliability, Distribution Network, Non-linear loads, Utility, Customer.

INTRODUCTION

Power Quality (PQ) is undoubtedly a fundamental component of the key performance index for power supply business in recent time. Power quality issues on distribution system are complex, wide reaching and expensive to mitigate in developing countries like Nigerian distribution network. Continuous power supply at the required quality remains a critical challenge for Nigeria despite her abundant energy resources. An electricity supply nowadays is treated as a product and like any other electrical power has to comply with specific quality requirements. Various stakeholders -Utilities, appliance manufacturers, and residential customers need adequate information on power quality. Whether or not the customer is likely to suffer from power quality problems depends on the quality of voltage at the terminal point, types of loads in customer's installation and the sensitivity of customers' equipment to various kinds of disturbances. Often time, the quality of electricity provided to customers is not always suitable for use by all customer equipment and thus the need for customer guide (ENA, 2010).

PQ is the degree of conformation to the expected function under stated condition over a specified period. It is said to be a broad field which covers all aspects of power systems engineering, from transmission and distribution, to end user problems (Edomah, 2012). It can be considered as power that does not impair the operation of a customer's equipment. While reliability ensures the presence of *sufficient* voltage at the equipment terminal, PQ ensures that the *value* of the voltage (and other electrical parameters) as a percent of nominal at the terminal is within the stipulated standard. Thus the new concept of PQ requires a power that is reliable, efficient, secure, and clean and meet required standard. Modern power supply studies therefore require both quantitative and qualitative approach. Reliability, which is the probability that a product or service will operate properly for a period of time (designed life) under the designed operating conditions (such as temperature or voltage) without failure means that the reliability of power in a distribution network is a measure of continuity of such power at desired quality. From this definition, it is required that the supply is not only regular but also of required quality. Therefore, with the dramatic increases and consumer dependency upon microprocessor-controlled loads, power quality has become critical measures of performance. Performance indicators that go above and beyond traditional reliability indices such as SAIDI and SAIFI are consequently needed to fully articulate performance of the electric supply today.
The variation of voltage and current which defines the power quality can either be in terms of magnitude or waveform shape (distortion). As a result of new power electronic products entering the market, in order to meet customer satisfaction,

quantity is not enough but quality as well. Therefore, quality should be overriding factor more so in the era of "9Rs" of reliability.

Traditionally, power quality is a measure of the purity of the electric waveform on power lines (Galvin Iniative, 2011). A power quality event occurs when one of the waveforms differs from a pure sinusoidal waveform or one or two phases of power are lost. Power quality events can last from a few cycles to a few seconds and can be caused by lightning strikes, falling trees, utility operations and operations from other customers such as disturbances from starting a large motor (Rouse and Kelly (2011). Nowadays, it is being used as a set of metrics used to benchmark the quality of service provided to a customer. It means a voltage and frequency compatible with the customer's end-use equipment. The degradation in power quality and increase in its awareness is being fueled by continuous increase in demand for non-linear power electronics devices. Figure 1 shows a single line diagram of a typical distribution network with loads classification into linear and non-linear.

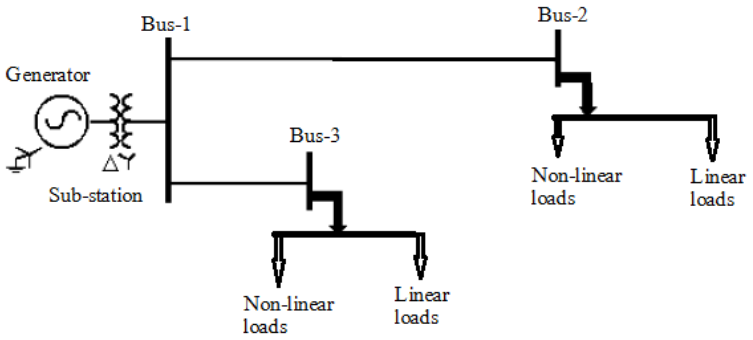

Fig. 1: Distribution network with linear and non-linear loads

Technically, the quality of supply in a distribution network can be affected by issues such as voltage dips, swells and spikes, and television or radio interference. Figure 2 shows details of conventional power problems classification as quality and reliability.

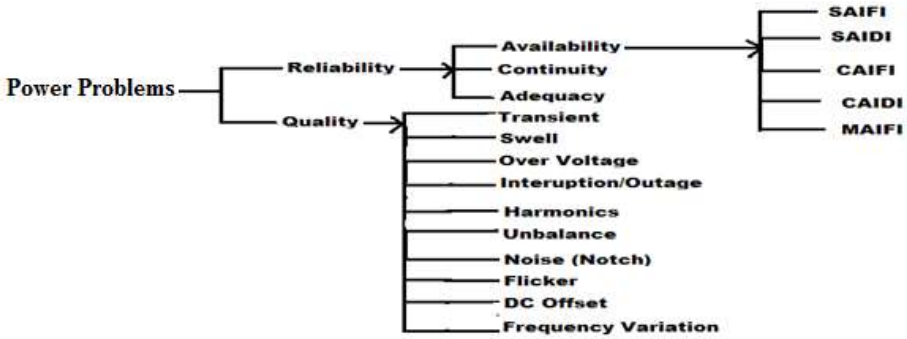

Fig. 2: Classification of common Power problems.

Erstwhile, reliability is often referred to as continuity of supply while power quality is synonymous with voltage quality and Customer service is called Commercial quality. However, attempt is now being made to merge the reliability and quality together as power quality issue. Figure 3 shows the relationship between the two. Reliability is thus a subset of power quality as service reliability is an index of power quality.

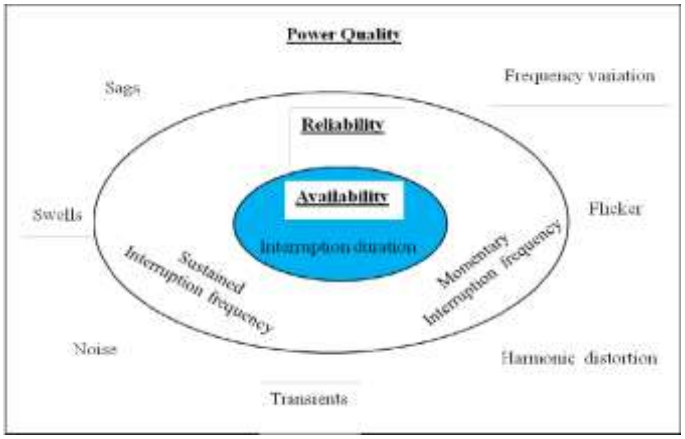

Fig 3: Reliability as a subset of power quality (Dorji, 2009)

Generally, power quality problems in any network can be divided into two: from the supply sources (utilities) or from the end-users (customers). Some problems are network related (for example, the result of a network limit or fault), but others may be traced to an environmental issue or to a network customer. Network businesses report on the technical quality of supply by disaggregating complaints into their underlying causes and categorizing them. Enhancement of supply voltage quality is a key function of realizing the future efficient smart grid. In the event of significant distortion of the supply network voltage at the point of common coupling (PCC) between the electricity supplier and customer, the source of disturbance should be located. This becomes of particular significance when formulating contracts for electric power supply or charging for worsening the quality of supply (NER, 2002). In many cases also a quantitative determination of the supplier and customer(s) contribution to the total voltage distortion at the PCC is required.

Every utility should be assessed by quality of service rendered in the process of electricity supply. Attempt is now being made to redefine this quality of service in electricity supply with the relationship between Network & Customer now being referred to as Commercial Quality in UK. Such practice is yet to be captured in developing countries like Nigeria and the need for that has been emphasized in literature (Ogunyemi and Adejumobi, 2016).

Also, further attempt has been made to divide quality of supply into technical aspects and organizational aspects (Tesařová, 2011). In the paper, continuity of supply (reliability) and power quality were classified under technical aspect while quality of service which has to do with customer service and regulatory issues was put under organization. Models of interface between utilities and customers have been suggested in literatures (NER, 2002; Ogunyemi and Adejumobi, 2016). Thus there`s need to explore all possible means both technically and economically in order to enhance optimal accommodation of nonlinear devices in a weak distribution network. Table 1 shows contributions from both Utility and Customer towards power quality system.

Table 1: Contributions of Utility and Customer towards PQ

S/N	Utility	Customer
1.	Voltage level	Power Factor (PF)
2.	Voltage unbalance	Current unbalance
3.	Voltage harmonics	Current harmonics
5.	Quality of service (QS)	Quality of utilization (QU)

Though the study of power quality has generally been classified into three areas as (EPRI, 2005; CEER, 2011) as i) Reliability or Continuity of supply ii) Power quality or Voltage quality and iii) Customer service or Commercial quality; no effort has been made to unify them as proposed in this paper.

Proposed Total PQ Concept

The term “Power quality” is a combination of two words- power and quality. Technically, power itself is a product of voltage and current. On the other hands, quality is a word stating the level of excellence. Since power is a product of voltage and current in electrical terms; then it implies that PQ is the combination of voltage quality (VQ) and current quality (IQ). Complementary to this is the assertion that quality of service by the utility company (DISCO) and quality of utilization by the consumer must be balanced for healthy power system. For instance, IEEE 519 standard insists that utility should give a voltage harmonics distortion level less than 5% provided customer limits their distortion to acceptable level. It is a condition of contract for supply that customer must avoid disturbing the network and other users. Therefore, In order to achieve optimum economic condition for nonlinear load on the low voltage distribution network, it is imperative that all possible technical measures should be addressed. This calls for baseline study in PQ issue involving supply side and demand side to see the total impact both technically and economically. The following terms are therefore proposed with definitions given for Total Power Quality (TPQ) concept to embrace all the technical and non-technical terms.

1) Supply Quality

Supply Quality (SQ) is defined as combination of voltage quality and service quality. It is an indication of quantity and quality of supply that involves both technical (voltage quality (VQ)) and non-technical (i.e. quality of service (QS)). It can be expressed mathematically as:

$$SQ = VQ + QS \quad \text{---------- (1)}$$

2) Voltage Quality: This is entire combination of all voltage related problems in power system. Voltage Quality is a function of voltage magnitude (V_m), voltage variation (V_v), voltage harmonic distortion(V_h), unbalance voltage (V_{un}) and frequency (F) in the network including interruption (Int). This can be expressed as:

$$VQ = f(Vm, Vv, Vh, Vunb, F, Int....) \quad \text{---------- (2)}$$

Interruption or outage is an indication of zero voltage hence can be classified as voltage quality (It is usually expressed in reliability). While reliability deals with measure of quantity of supply, voltage quality on the other hand is a measure of purity of the supply. Hence, supply quality encompasses quantity and quality.

3) Quality of service or Service Quality: This deals with aspect of interaction or interface between the power networks to its entire customer. It has to do with the methods of billing and tariff systems, response of utility to customer's complaints and provision of incentive or rebate to customer etc. Customer service typically relates to the nature and quality of the service provided to electricity consumers. Customer service (referred to as "commercial quality" in Europe)

4) Utilization Quality (UQ)

This is quality of utilization from demand side as a complementary term to supply quality (SQ) from utility. It involves also technical (current quality (IQ)) and non-technical (i.e. quality of customer's response (QR)) in the power system. It is expressed as:

$$UQ = IQ + QR \quad \text{---------- (3)}$$

5) Current (I) Quality (IQ) is a measure of both magnitude of the load current consumption and how it degrades (distorts) the supply power. It is combination of fundamental current (I_f), harmonic current (I_h), unbalanced current (I_{UNB}) and power factor (PF). Distortion is majorly from NLD and PF is a measure of how effectively a load utilizes the current from an AC power system. Low PF is majorly from inductive load.

$$IQ = f(\mathrm{Im}, If, Ih, Iunb, PF, ...) \quad \text{---------- (4)}$$

6) Response Quality or Quality of response (QR) is a measure of feedback from customers. Indices include promptness of payment, perception and satisfaction by the customers.

7) Total Power Quality (TPQ)

This is a term encompassing both technical and non-technical terms in electricity distribution network. That is:

$$TPQ = SQ + UQ \quad \text{---------- (5)}$$

Total PQ is thus a combination of supply quality and utilisation quality. It can also be said to be the combination of technical (real) quality and non-technical (abstract) quality.

8) Technical PQ is a product of voltage quality and current quality. This agree with formal definition of power as product of voltage (V) and current (I).

$$PQ_{TR} = f(VQ, IQ) \quad \text{---------- (6)}$$

9) Non-technical PQ is a function of service quality and response quality.

$$PQ_{TR} = f(VQ, IQ)$$

$$TPQ = f(VQ, IQ, QS, QR) \quad \text{---------- (7)}$$

Thus, while technical PQ can be said to be a measure of the purity of the electric waveform on power lines; total PQ deals with both technical and non-technical aspects of power quality.

10) Total Power Quality Triangle (PQT)

The whole concept can be shown in power quality triangle as shown in fig 4 where P, Q, and T represent power (quantity), quality and total power quality respectively.

From the PQT, the concept has also captured the essence of modern power supply which is combination of power (quantity) and quality. The concept has thus shared the responsibilities between the supply ends and the end–users. In terms of policy making and regulatory standards, both sides can be adequately considered with respect to their contributions in the power network.

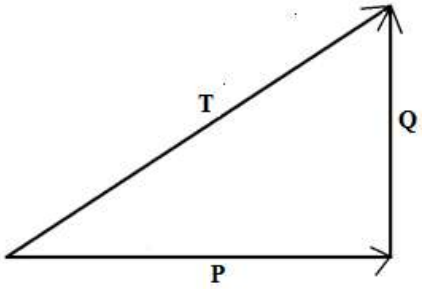

Fig. 4: Total Power Quality Triangles

Total Power Quality as a technical term that has practical implications on the performance of the Utility and productivity of end-user can be used to assess both the Supplier and Consumers. In other words, utilities equipment will be assessed based on supply quality parameters while appliances at consuming ends will be assessed on utilization parameters. In this way, customer with various loads can be identified. Linear loads for instance are known to have low distortion while non-linear loads have high distortion.

The triangle equally depicts the trend in power system development from early reliability era to present day power quality. It is the path to be embraced as solution to modern crisis especially in less developing countries with low reliability. The horizontal represents the reliability while the vertical represents the power quality. Thus, total PQ embraces both the reliability and power quality.

Conclusion

This paper has examined reliability and power quality in the distribution network in the presence of linear and non-linear loads. Supply quality which is made of voltage and service qualities and Utilisation quality made of current and response qualities are proposed to cater for the emerging trend. These terms are further classified as technical quality and non-technical qualities to further reflect and capture vividly the concept of total power quality concept. The concept will be useful especially in the third world where reliability is still a major issue. It will also be useful for power system planning and development such as in formulation of policy and development of software. However, there is need for appropriate metric for the TPQ that will be universal to derive the full benefit of the terms.

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