Review Power Quality Issues

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Abstract

This paper introduces the terminology and various issues related to 'power quality'. The interest in power quality is explained in the context of a number of much wider developments in power engineering: deregulation of the electricity industry, increased customer-demands, and the integration of renewable energy sources. After an introduction of the different terminology power quality disturbances are discussed in detail: voltage dips and harmonic distortion. For each of these two disturbances, a number of other issues are briefly discussed, which are characterisation, origin, mitigation, and the need for future research.

Keywords: Power quality, Harmonic distortion, Voltage dips

1. Introduction

Power Quality (PQ) has become increasingly important for industrial and commercial electric power customers, particularly as today's manufacturing and control processes rely on computerized equipment which is sensitive to power system interruptions and disturbances. Power Quality is simply the characteristic of the energy or electrical supply by the utility which might affect the load (electrical equipments that are connected for an electrical supply) or vise versa (Faisal, 2005).

Power quality issues have in recent years received an increasing attention both by the end users and utilities alike. This paper aims to elaborate power quality issues and the impact it may have to the users and utilities as utilities are bound in most cases to a pre-determined quality supply agreement.

2. Effects of Power Quality to Industrial Users

Electrical power is perhaps the most essential raw material used by commerce and industry today. It is an unusual commodity because it is required as a continuous flow it cannot be conveniently stored in quantity and it cannot be subject to quality assurance checks before it is used. It is, in fact, the epitome of the 'Just in Time' philosophy in which components are delivered to a production line at the point and time of use by a trusted and approved supplier with no requirement for 'goods in' inspection. Thus, it is necessary for end customer to have good control of the onwards supply component specification. The reliability of the supply must be known and the resilience of the process to variations must be understood. In reality, of course, electricity is very different from any other product it is generated far from the point of use, is fed to the grid together with the output of many other generators and arrives at the point of use via several transformers and many kilometers of overhead and possibly underground cabling. Where the industry has been privatized, these network assets will be owned, managed and maintained by a number of different organizations. Assuring the quality of delivered power at the point of use is no easy task and there is no way that sub-standard electricity can be withdrawn from the supply chain or rejected by the customer.

From the consumers' point of view the problem is even more difficult. There are some limited statistics available on the quality of delivered power, but the acceptable quality level as perceived by the supplier (and the industry regulator) may be very different from that required, or perhaps desired, by the consumer. The most obvious power defects are complete interruption (which may last from a few seconds to several hours) and voltage dips or sags where the voltage drops to a lower value for a short duration. Naturally, long power interruptions are a problem for all users, but many operations are very sensitive to even very short interruptions. Examples of sensitive operation are (Mertens Jr., et al., 2004):

- Continuous process operations, where short interruptions can disrupt the synchronization of the machinery and result in large volumes of semi-processed product. A typical example is the paper making industry where the clean-up operation is long and expensive.

- Multi-stage batch operations, where an interruption during one process can destroy the value of previous operations. An example of this type is the semiconductor industry, where the production of a wafer requires a few dozen processes over several days and the failure of a single process is catastrophic.
- Data processing, where the value of the transaction is high but the cost of processing is low, such as share and foreign exchange dealing. The inability to trade can result in large losses that far exceed the cost of the operation

3. Common Power Quality Problems

So, what do we mean by 'power quality'? A perfect power supply would be one that is always available, always within voltage and frequency tolerances, and has a pure noise free sinusoidal wave shape (Felce, et al., 2004; Pirjo, & Matti 2003). Just how much deviation from perfection can be tolerated depends on the user's application, the type of equipment installed and his view of his requirements. Power quality defects the deviations from perfection fall into six categories:

1. Voltage Fluctuation (flicker)
2. Harmonic Distortion
3. Power Frequency Variation
4. under or over voltage
5. Voltage Dips (or sags) and Surges
6. Transients

Each of these power quality problems has a different cause. Some problems are a result of the shared infrastructure. For example, a fault on the network may cause a dip that will affect some customers and the higher the level of the fault, the greater the number affected, or a problem on one customer's site may cause a transient that affects all other customers on the same subsystem. Other problems, such as harmonics, arise within the customer's own installation and may or may not propagate onto the network and so affect other customers. Harmonic problems can be dealt with by a combination of good design practice and well proven reduction equipment (Arrilaga, & Chen, 2001). Electricity utilities argue that critical users must bear the costs of ensuring supply quality themselves rather than expect the supply industry to provide a very high reliability supply to every customer everywhere on the network (Mertens Jr., et al., 2003). Such a guaranteed quality supply would require a very substantial investment in additional network assets for the benefit of relatively few customers (in numerical, not consumption, terms) and would be uneconomic. It is also doubtful whether it would be technically feasible within the current social and legal framework in which any customer is normally entitled to be connected to the supply and utility providers have the right to excavate roadways with the risk of cable damage. It is therefore a growing trend that critical industry consumer take steps to ensure that the quality of power delivered to his process is good enough, with the clear implication that this quality level may well be higher than that delivered to the plant by the utilities.

3.1 Transients

AC and DC drives, along with other electronic loads, can be very sensitive to transient voltages. The tolerance levels of these devices are often less than other loads such as standard motors. A major concern for transient voltages occurs with possible magnification of utility capacitor switching transients at low-voltage capacitor locations on customer power systems. Transient disturbances are high frequency events with durations much less than one cycle of the supply (Arrilaga, & Chen, 2001). Causes include switching or lightning strikes on the network and switching of reactive loads on the consumer's site or on sites on the same circuit. Transients can have magnitudes of several thousand volts and so can cause serious damage to both the installation and the equipment connected to it. Electricity suppliers and telecommunications companies go to some effort to ensure that their incoming connections do not allow damaging transients to propagate into the customers' premises. Nevertheless, non-damaging transients can still cause severe disruption due to data corruption. The generation and influence of transients is greatly reduced and the efficacy of suppression techniques greatly enhanced where a good high integrity earthing system has been provided. Such an earthing system will have multiple ground connections and multiple paths to earth from any point, so ensuring high integrity and low impedance over a wide frequency band.

3.2 Voltage Sags and Momentary Interruptions

Voltage sag is widely recognized as one of the most important power quality disturbances (Wahab, & Alias, 2006). These can be caused by the utility or by customer loads. When sourced from the utility, they are most commonly caused by faults on the distribution system. Voltages sag as shown in Figure 1 is a short reduction in *rms* voltage from nominal voltage, happened in a short duration, about 10 ms to seconds (Dugan, et al., 2003).

Can be single or three phases, Depending on the design of the distribution system, a ground fault on one phase can cause a simultaneous swell on another phase. The IEC 61000-4-30 defines the voltage sag (dip) as a temporary reduction of the voltage at a point of the electrical system below a threshold (IEEE, 1993). According to IEEE Standard 1159-1995, defines voltage sags as an *rms* variation with a magnitude between 10% and 90% of nominal voltage and duration between 0.5 cycles and one minute (IEEE Working Group P1346, 1994).

Voltage sag normally happens at the feeder adjacent to an unhealthy feeder. This unhealthy feeder are caused by two factors which are short circuits due to faults in power system networks and starting motor which draw very high lagging current. Both of these factors are the main factor creating voltage sag as power quality problem in power system.

Increased sensitivity of power electronic equipment such as programmable logic controller (PLC), adjustable speed drive (ASD), coupled with the high likelihood of voltage sags and interruptions, has resulted in these being the most visible power quality events. Adjustable-speed drives, computers, office equipment, programmable controllers, and induction heating furnaces can be extremely sensitive to these events. Typically, sags occur when there are temporary faults on the utility power system, resulting in a reduction in the voltage level (McGranaghan, et al., 1993). Equipment sensitivity to these events is important because nuisance tripping of sensitive industrial loads can cause equipment downtime, reduce productivity, and hurt your bottom line. There are many ways in order to mitigate voltage sag problem. One of them is minimizing short circuits caused by utility directly which can be done such as with avoid feeder or cable overloading by correct configuration planning. Another alternative is using the flexible ac technology (FACTS) devices which have been used widely in power system nowadays because of the reliability to maintain power quality condition including voltage sag (Bollen, 2000). There are many devices have been created with purpose to enhance power quality such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-STATCOM) and Uninterruptible Power Supply (UPS). All of these devices are also known as custom power devices.

3.3 Harmonics Distortion

Harmonic distortion of the voltage and current results from the operation of nonlinear loads and devices on the power system, the nonlinear loads that cause harmonics can often be represented as current sources of harmonics (Dugan, et al., 1996). The system voltage appears stiff to individual loads and the loads draw distorted current waveforms. Table 1 illustrates some example current waveforms for different types of nonlinear loads. The weighting factors indicated in the table are being proposed in the Guide for Applying Harmonic Limits on the Power System for preliminary evaluation of harmonic producing loads in a facility.

Harmonic voltage distortion results from the interaction of these harmonic currents with the system impedance. The harmonic standard (IEEE 519-1992), has proposed two way responsibilities for controlling harmonic levels on the power system.

1. End users must limit the harmonic currents injected onto the power system.
2. The power supplier will control the harmonic voltage distortion by making sure system resonant conditions do not cause excessive magnification of the harmonic levels.

Harmonic distortion levels can be characterized by the complete harmonic spectrum with magnitudes and phase angles of each individual harmonic component. It is also common to use a single quantity, the Total Harmonic Distortion, as a measure of the magnitude of harmonic distortion. For currents, the distortion values must be referred to a constant base (e.g. the rated load current or demand current) rather than the fundamental component. This provides a constant reference while the fundamental can vary over a wide range

Harmonic distortion is a characteristic of the steady state voltage and current. It is not a disturbance. Therefore, characterizing harmonic distortion levels is accomplished with profiles of the harmonic distortion over time (e.g. 24 hours) and statistics. Figure 2 illustrates a typical profile of harmonic voltage distortion on a feeder circuit over a one month period.

3.4 Voltage Fluctuation

Flicker is the impression of unsteadiness of visual sensation induced by a light stimulus, the luminance or spectral distribution of which fluctuates with time. Usually, it applies to cyclic variation of light intensity of lamps caused by fluctuation of the supply voltage. Flicker is symptoms of voltage fluctuation which can be caused by disturbances introduced during power generation, transmission or distribution, but are typically caused by the use of large fluctuating loads, i.e. loads that have rapidly fluctuating active and reactive power demand (Power Quality' Working Group WG2, 2000). The following sections examine the nature of voltage fluctuations, their causes, and effects, methods of measurement, mitigation and applicable standards.

3.4.1 Causes of Voltage Fluctuations

The classification of *rms* voltage variations is shown in Figure 3 as a plot of voltage against duration of disturbance. The hatched areas correspond to the voltage changes considered in this paper.

For any supply line, the voltage at the load end is different from that at the source. This can be demonstrated from the per-phase equivalent circuit in Figure 4a. The relationship (1, below) illustrates how the value of the voltage difference ΔU, defined in Figure 4b, can be derived from the phasor diagram and simple geometrical rules.

$$\frac{E-U_0}{U_0} \approx \frac{\Delta U}{U_0} = R_S \frac{P}{U_0{}^2} + X_S \frac{Q}{U_0^2} =\approx R_S \frac{P}{U_0^2} + \frac{Q}{S_{ZW}} \tag{1}$$

Where:

E	= The source voltage
U_0	= The voltage at the load terminal
I_0	= Current
Z_S, X_S, R_S	=Equivalent impedance, reactance and resistance of the line respectively
P, Q	=active and reactive power of the load
S_{ZW}	=short-circuit power at the point of load connection (S*SC*).

Assuming that the equivalent resistance of the line is negligibly small compared with its reactance (*XS* > 10*RS*), which holds true for practical MV and HV supply systems, the following relationship defines the relative value of voltage change at the load-end of the line:

$$\frac{\Delta U}{U_0} \cong \frac{Q}{S_{ZW}} \tag{2}$$

Depending on its cause, voltage change ΔU can take the form of a voltage drop having a constant value over a long time interval, a slow or rapid voltage change, or a voltage fluctuation. Voltage fluctuation is defined as a series of *rms* voltage changes or a cyclic variation of the voltage waveform envelope as shown in Figure 5.

The defining characteristics of voltage fluctuations are:

- The amplitude of voltage change (difference of maximum and minimum *rms* or peak voltage value, occurring during the disturbance),
- The number of voltage changes over a specified unit of time, and
- The consequential effects (such as flicker) of voltage changes associated with the disturbances.

4. Conclusion

To overcome the negative impact of poor power quality on equipment and businesses, suitable power quality equipment can be invested. Identifying the right solution remains the first step. Many power quality problems are easily identified once a good description of the problems is obtained. Unfortunately, the tensions caused by power problems often result in vague or overly dramatic descriptions of the problem. A power 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. The auditor normally will check the quality of the AC voltage itself, and consider the impact of the utility's power system. Many businesses and organizations rely on computer systems and other electrical equipment to carry out the mission critical functions, but they aren’t safeguarding against the dangers of an unreliable power supply. It is time utilities as well as businesses engage in more proactive approach to power quality treats by engaging in power quality analysis.

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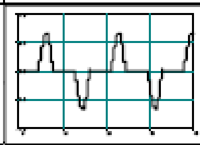
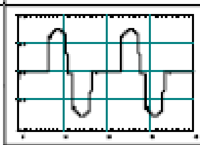
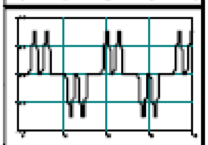
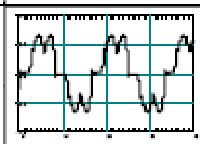
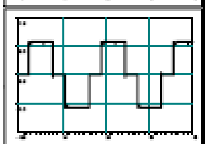
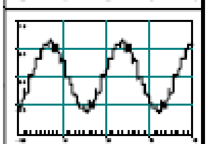
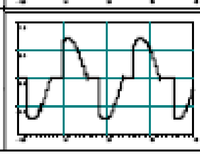
Table 1. Example current waveforms for various nonlinear loads

Type of Load	Typical Waveform	Current Distortion	Weighting Factor (W_i)
Single Phase Power Supply		80% (high 3rd)	2.5
Semiconverter		high 2nd,3rd, 4th at partial loads	2.5
6 Pulse Converter, capacitive smoothing, no series inductance		80%	2.0
6 Pulse Converter, capacitive smoothing with series inductance > 3%, or dc drive		40%	1.0
6 Pulse Converter with large inductor for current smoothing		28%	0.8
12 Pulse Converter		15%	0.5
ac Voltage Regulator		varies with firing angle	0.7

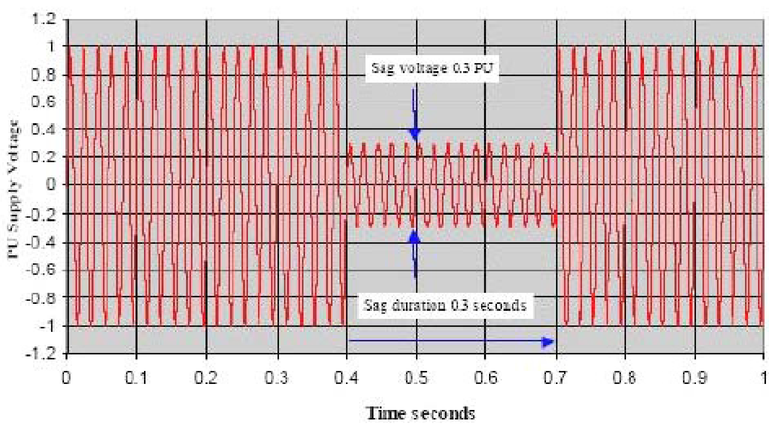


Figure 1. Voltage sag waveform

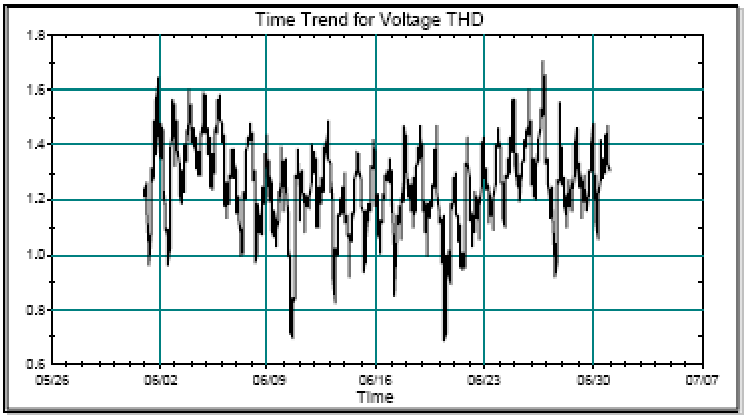


Figure 2. Example profile of harmonic voltage distortion on a distribution feeder circuit

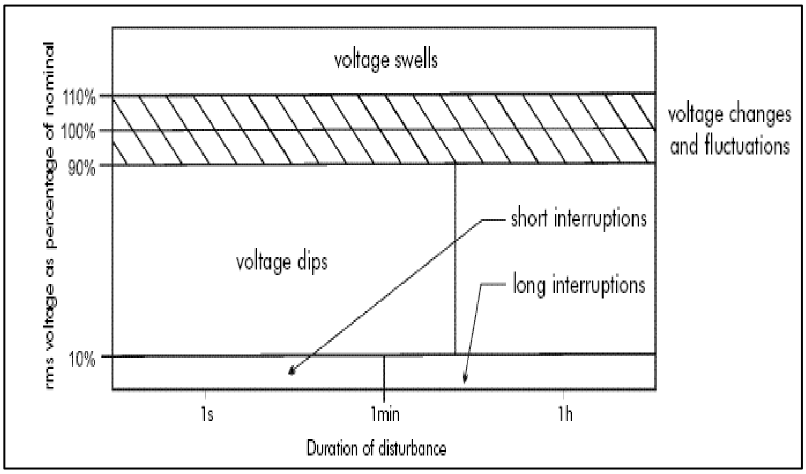


Figure 3. Classification of voltage variations

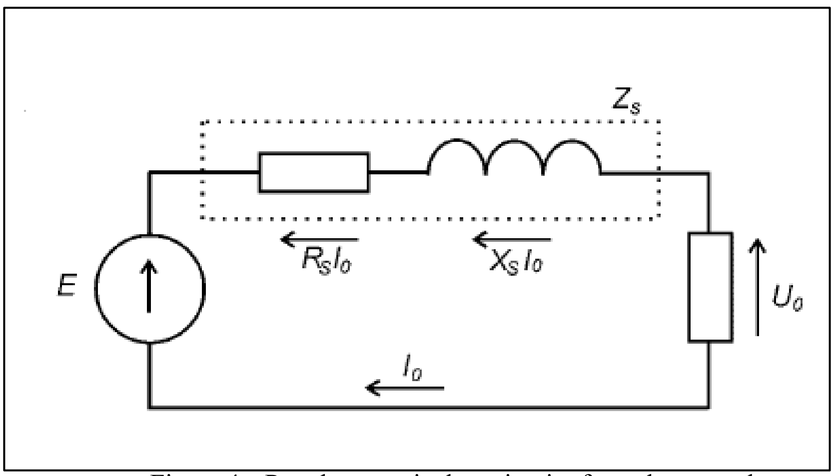


Figure 4a. Per phase equivalent circuit of supply network

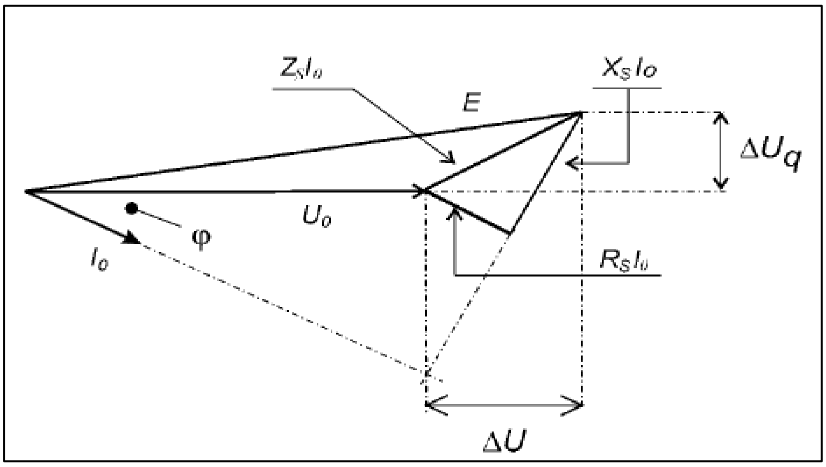


Figure 4b. Per phase equivalent circuit of phasor diagram for a resistive inductive load E U_0

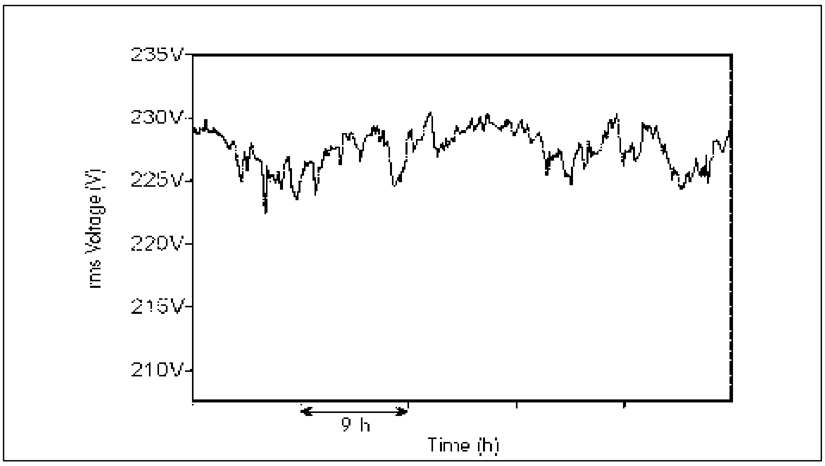


Figure 5. Example of rms voltage fluctuation