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# A critical review-power quality concerns

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## ABSTRACT

*Power system quality concerns is the art and science of analyzing power system performance within a facility to determine potential problem areas or to better understand known problems in an electrical distribution system. This mainly explain the various types of power disturbances such as for irritant disturbances, blinks, sags, dips, swells, transients, impulse transients, DC offset, harmonics, notching, surges, voltage fluctuation, flickering, spikes, phase loss, outages, interruptions, under/over voltages etc. It also explains the impact of the disturbances for the power system operation. The emphasis has been given on data collection to understand power quality concerns. The primary sources of data collection based on technicians who spent most of their time near power system equipment. It also introduces terminology and various issues to "Power Quality".*

**Keywords:** *Power Quality, Data Collection, and Power System disturbances.*

## INTRODUCTION

Electric power quality study consists of determining momentary variation in voltage, current and frequency relative to their steady state values under consideration. If the sensitive equipment work as planned then there is no need to conduct power quality survey, otherwise it becomes unavoidable. Restrictions on AC supply lines are more severe today as compared to past but the loads are creating far more transients and distortions than the older versions of the similar equipment. Alternatively, today's industrial load themselves destroy power quality and require utility to provide fresh clean AC power supply. It has been observed that the loads more sensitive to power quality are often the source of its garbage. Among disturbances voltage sags, caused by usually short circuit faults, are far more significant and frequent than impulses, harmonics, outages, surges, spikes and impulses. Voltage sags and surges can garble computer system data even if the disturbance transient time is sufficiently fast. System hardware is also affected very badly if the utility spinning reverse is low. Momentary interruptions do cause operational problems for sensitive industrial equipment. Like voltage sags transient over voltages can also disrupt operation of electronic equipment. Short duration transients and momentary harmonic resonance are the most difficult power quality problem to identify and to eliminate [1].

Electric power quality is a subject of mysterious stories inviting power protection and control engineers to ponder the unknown causes and solutions. Power quality problems such as sags or dips, swells, harmonic resonance, lightning impulses, spikes and noise are naturally coming and self clearing type problems except few sustained troubles like flicker and total harmonic distortion. Normal domestic users are not affected by the power quality evils in their power supply. Power quality problems affect the large industrial manufacturing organizations that work day and night to meet the demand of their customers. Typical examples of such organizations may include large petrochemical, fertilizer, steel, chemical, pharmaceutical and paper mills. Besides the above, it is critical service departments such as hospitals, water supply, gas supply, military security system and large civil services offices may be affected by power quality problems. Lot of research has been carried out on power quality issues since last two decades but the fact is that the cost of downtime increasing (billions of dollars per year). Half of the large corporations rate their downtime costs at over RM 4000 per hour and 9% of corporations estimate the costs to be over RM200, 000 per hour!  US industries are bold to announce the losses but many other countries try to hide their deficiencies like China did with SARS and speak when they have suffered irredeemable losses. Choosing the right power protection is complex and confusing. Most power quality experts also provide protection solutions rendering the survey nothing more than a manipulative sales piece designed to get you to buy their products [1].

Measuring Power Quality requires a complex data acquisition tool because the inexpensive meters are too slow for today’s faster computers. Hand-held meters and other low cost measurement tools offer only a limited range and often indicate that the site is good when in reality it could be costing you money. In summary, use an inexpensive meter when you want to prove that the site is good and not gather data that leads to a solution. Customer’s power, grounding and HVAC systems are rarely properly prepared for today’s computer based systems and once the systems are installed, they believe that the manufacturer has assumed the responsibility to make the system work. The typical cost of a “no-trouble” service call is estimated at RM4, 800. Often, many Field Service Engineers replace good circuit boards only because they don’t know what else to do. The typical cost for a detailed power survey using sophisticated test equipment usually costs over RM14, 000 per site [1].

The only thing worse than having a system failure is not knowing what caused it. With PQ monitoring, though, you can eliminate some of your troubleshooting headaches. It would be nice to go to bed at the end of the day and know that you’re going to be able to sleep through the night. It would be nice to know there isn’t a possibility you’ll get a phone call just as you finally fall asleep. If you’re a plant engineer or technician, though, you know you’ll never enjoy these happy fantasies. But you also know that being roused from your slumber in the middle of the night by a phone call informing you that production has unexpectedly stopped at your management why it happened and more importantly, why it won't happen again. The cause could be one of any number of things, but you don't have the rest of the week to troubleshoot the entire plant. This work stoppage may have already cost the company thousands of dollars in lost materials and production downtime. You could try to diagnose the problem on your own, but unless you're an expert in power quality and you probably aren't your hunches and predictions won't carry much weight [1].

Of course, none of this would be a problem if you had a power quality monitoring system. If you did, at the same time that phone call woke you and alerted you to the problem, you could have received a page informing you that voltage sag occurred on the motor circuit serving the conveyor line at 1:30p.m., stopping production for 15 sec. But you don't have a PQ monitoring system, then you have to go to the plant manager empty handed and buy yourself some time until you can troubleshoot the system and pinpoint the problem [1].

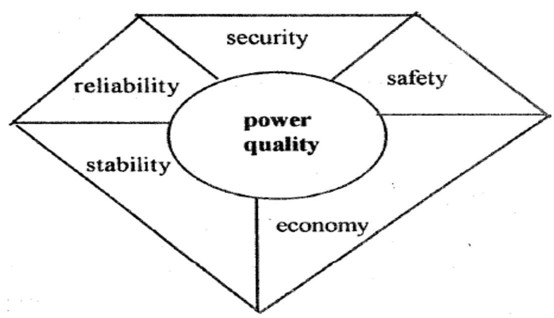


Figure 1. Power Quality at a Glance.

## What is Power Quality?

Any electric power supply problem resulting in voltage, current or frequency deviations that leads to failure or misoperation of customer equipment. So power quality defined as deviation of voltage, current and frequency from the standard rated values when it starts affecting the end users [1]. Mostly the deviation is quite small and end users are not affected but sometimes deviations are beyond the tolerance of the equipment and as a result in misoperation. Power quality problems that practically affect the customer equipment are voltage sags 92%, harmonics 5%, and transitories 3%. If somebody says that power quality is the quality of voltage then he might be right. Or simply if we say that power quality is the study of voltage sags then too it is correct. Depending upon the degree of severity of problems of power system [1].

Good power quality is not easy to define because what is good power quality to a refrigerator or motor may not be good enough for a personal computer. For example, a short (momentary) outage would not noticeably motor, lights etc, but could reset a computer. However, it may be defined, as “Power quality is the degree to which both the utilization and delivery of electric power affect the performance of the electrical equipment”. Graphical representation of typical power quality parameters is given in Figure 2 [1, 2].

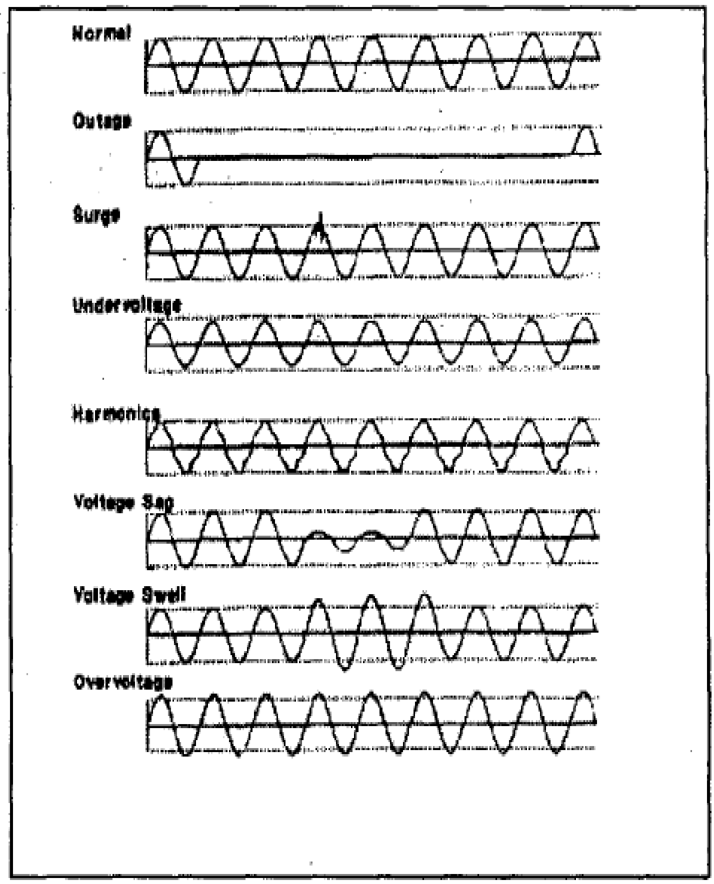


Figure 2.Graphical representations of power quality parameters.

The term power quality is not easily and fully comprehendable since it encompasses electrical power with all its innumerable good and bad attributes. This utility oriented factor is a subjective one of many objectives with various constraints. In the eyes of Power System Engineer it focuses on the broad perspective of economy, stability, reliability, security and safety. Many more properties still remain to be explored. One optimistic interpretation of power quality is the 'total goodness of a power system' with the bad traits being eliminated or kept to a minimum. It conveys the significance of the healthy well being, a desirable state of a power system. A good power system is appreciable. A better is desirable. The best is laudable. Power quality concerns such modern power system shown in Figure 1 [2].

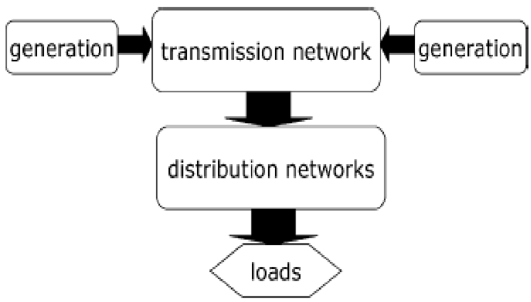


Figure 3. Classical model of the power system.

Classically, the aim of the electric power system is to generate electrical energy and to deliver this energy to the end user equipment at an acceptable voltage. The term power quality came in use referring to the other characteristics of the supply voltage i.e. other than long interruptions. But, immediately, the first confusion started as utilities included the disturbances generated by the customers in the term ‘power quality’. This classical model of the power system, as it can be found in many textbooks shown in Figure 3 [3].

In Figure 3 the electric power network connects some or many customers. Customers may generate or consume electrical energy or even both albeit at different moments in time. Different customers have different demands on voltage magnitude, frequency, waveform, etc. Different customers have different patterns of current variation, fluctuation and distortion, thus polluting the voltage for other customers in different ways. The power network in Figure 4 could be a transmission network, a distribution network, an industrial network, or any other network owned by one single company. For a transmission network, the customers are, e.g. generator stations, distribution networks, large industrial customers (who could be generating or consuming electricity at different times, based on the electricity price at that moment), and other transmission networks. For a distribution network, the customers are currently mainly end-users that only consume electricity, but also the transmission network and smaller generator stations are customers. Note that all customers are equal, even though some may be producing energy while others are consuming it. The aim of the network company is only to transport the energy, or in economic terms: to enable transactions between customers [3].

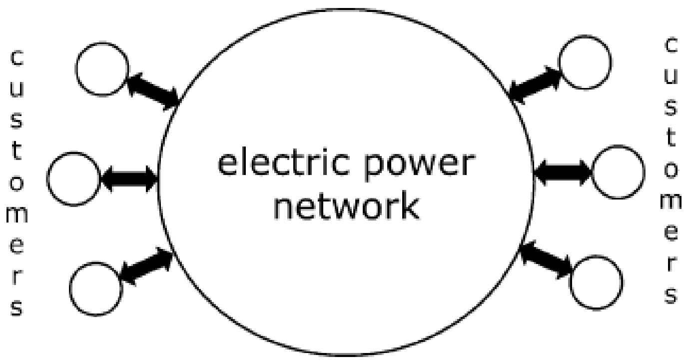


Figure 4. Modern model of the power system.

## Why Power Quality is Important?

One important contributing factor to nation's slow pace of development unsatisfactory industrial growth is the poor quality of electrical power. This power is a basic essential attribute and the advancement of any society is measured by the efficient supply and use of this precious commodity. Forced power cut, frequent shut down, major power break down in the grid, outages of the generators and transmission lines on a large scale, unexpected blackouts of long duration, unprecedented load shedding and consequent pitiable state of voltage and frequency regulations, are some of the regularly experienced flaws.

Besides the above, a better power quality is not only in the interest of the consumer but it is beneficial for the supplier/distributor also. Modern industrial process and extensive automation, requires a large use of sensitive electronic devices such as programmable logic controllers (PLCs), sensors, microprocessors, process controllers, relays, transducers etc. These devices allow executive complex and delicate operations, but at the same time are very sensitive to electric perturbation. A clean and a continuous power supply are the lifeline of modern industry and are of the same importance for the utilities. As any electric perturbation/interruption not only halts the industrial production but it also results indirect revenue loss to the utility.

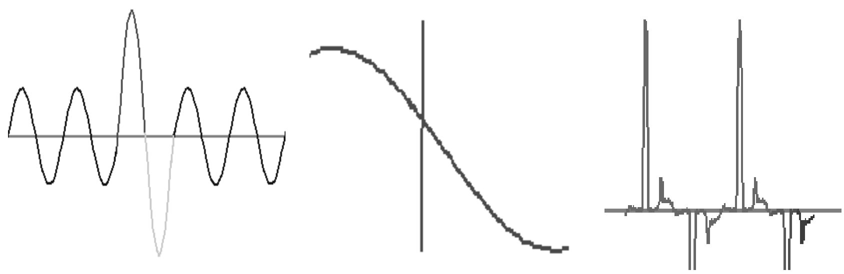

Figure 5. Oscillatory transients.

**Definition of Power Quality Terms**

Large industrial consumers expect utilities to supply clean power whereas in practice supply at generator terminals may be clean but at consumer end it is no more sinusoidal. It is possible for a utility to supply reliable and dirty power, whereas it is not possible for utility to supply, unreliable but clean power. Customer electronic equipment is sensitive to disturbances riding over the sinusoidal clean power. One solution is to install power line conditioners at consumer premises to filter out the undesirable disturbances or go for ride-through equipments to live with the dirty power is mixture of pure sinusoidal as well as may other voltage, current and frequency disturbance originating from utility as well as customer loads.

- **Clean power:** A perfectly clean power will have a perfectly sinusoidal voltage of constant amplitude and frequency. The wave shapes are supposed to be free of harmonics, noise and transients.

- **Dirty power:** A power supply with varying amplitude, frequency or wave shapes is known as dirty power. Clean power becomes dirty by interaction of utility switching, customer loads and natural forces.

- **Under voltage:** Under voltage is a sustained low voltage condition outside the normal tolerance. It may be caused by circuit overloads, poor voltage regulation, and intentional voltage reductions by utility.

- **Voltage dip:** Motor starting or short circuit faults on utility networks usually cause Voltage dips. The term dip may be associated to motor starting.
- **Voltage sag:** Voltage sag is a momentary decrease in voltage outside the normal tolerance. Voltage sags by definition, are associated with large motor starting. However, practically words voltage sags and sags refer to momentary under voltage condition and mean the same.

- **Voltage drop:** It is difference of voltage between sending and receiving ends. The reduction in voltage during sag or dip may be called as voltage drop.

- **Interruption:** A momentary collapse of voltage to zero is called interruption.

- **Outage:** It is a complete loss of power. It may be caused by a permanent fault on the line. Difference between interruption and outage is due to the time involved in their occurrence.

- **Voltage modulation:** It is a periodic increase and decrease of amplitude of nominal voltage. Periodic loads such as pumps may cause it.

- **Voltage imbalance**: It is the difference in phase voltage magnitudes of poly phase lines. Unequal loading of phases of lines is often the cause of voltage imbalance. Besides it broken neutrals on distribution transformers also cause this condition.

- **Phase angle imbalance:** It is the deviation from the normal 120º or 240º between three phase voltages. It may be caused by uneven distribution of loads among the phases.

- **Blackout:** It refers to complete loss of power or collapse of voltage for several minutes.

- **Brownout:** It is international lowering of utility voltage to reduce loading on the system.

- **Harmonic:** It is the periodic deviation from normal sine wave profile. Harmonics are caused by the nonlinear operation of devices such as power converters, inverters and arc furnaces.

- **Flicker:** It is voltage fluctuation per unit time. It is caused by arc furnace type loads and affects the normal visibility due to light variation. It is characterized through lamp illumination.

- **Over voltage:** It is a sustained condition of high voltage outside the normal tolerance. Over voltage may be caused by poor voltage regulation, excessive voltage drops on lines, low rated conductors of cables or overloading.

- **Voltage swell:** A voltage swell is momentary increase in voltage outside the normal tolerance. Voltage swells are caused by sudden decrease or turning off the heavy loads.

- **Surge:** A surge is also known as impulse or spike. It is a short duration voltage increase caused by lightning or switching of specially inductive or capacitive load.

- **Transient:** It is a voltage pulse of high energy and short duration impressed upon the AC waveform.

- **Spike:** It is a short duration increase in voltage that appears on top of positive half cycle. Its duration is shorter than swell and is superimposed upon the sinusoidal positive half cycle.

- **Oscillatory transient:** It may appear for half cycle period to modulate the half cycle by increasing its frequency up to several Hz. Switching causes it.

- **Impulse:** It is a high-energy impulse superimposed upon the AC waveform due to lightning or failure of charged capacitors.

- **Electrical noise:** It is the distortion of normal sinusoidal power. Switching, radio transmitters, arcing furnaces and welding plants can cause electrical noise. It is further grouped into two categories.

- **Normal mode noise:** It is the voltage differential that appears between a power line and its accompanying neutral wire.

- **Common mode noise:** It is the voltage differential that appears between the ground and the neutral wire.

- **Rated voltage:** The voltage at which the performance and operating characteristics of apparatus are referred is regarded as rated voltage.

- **Nominal voltage:** It is the value of voltage assigned to a line or apparatus.

- **Susceptibility:** Temporary malfunctions of devices due to disturbances.

- **Vulnerability:** A permanent or temporary damage to the device due to occurrence of disturbance or fault on the supply system. For example under voltage relays are vulnerable to short duration voltage sags.

- **Transients:** A transient is a "momentary change in the voltage or current over a very short time. This short time is less than 1 cycle, or 16 ms (for 60 Hz) or 20 ms (for 50 Hz). More often, transients are measured in microseconds rather milliseconds. Frequently this transient is called a voltage "Spike". The transient has a separate beginning and end. It may occur often or even at regular intervals, but it will have a beginning and end.

A typical oscillatory transient is shown in Figure 5. The resolution to transients and transient-related problems is the installation of surge protection equipment. While some utilities install surge suppression equipment on their distribution lines it is still necessary for the customer to install equipment in their home or business. The only way to stop transients is to build a "Protective Fence" around each piece of sensitive electronic equipment or appliance.

According to IEEE standards an oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapidly. It is described by its spectral content or predominant frequency, duration, and magnitude.

- **Impulsive transient:** An impulsive transient is s sudden, non-power frequency change in the steady-state condition of voltage, current, or both, that is unidirectional in polarity (primarily either positive or negative). Impulse transients are normally characterized by their rise and decay times. These phenomena can also be described by their spectral content. For example, a 1.2/50μs 2 kV impulsive transient rises to its peak value of 2 kV in 1.2μs and then decays to half its peak value in 50 μs.

- **DC offset:** The presence of DC voltage or current in an AC power system is termed DC offset. This phenomenon can occur as the result of a geomagnetic or due to the effect of half-wave rectification. Incandescent light bulb life extenders, for may consist of diodes that reduce the RMS voltage supplied to the light bulb by half-wave rectification. Direct current in alternating current networks can be detrimental due to an increase in transformer saturation, additional stressing of insulation, and other adverse effects. DC offset may also appear during fault. Example of a typical DC offset is shown in Figure 6.

- **Notching:** Notching is periodic voltage disturbance caused by the normal operation of power electronic devices when current is commutated from one phase to another. Voltage notching represents a special case that falls between transients and harmonic distortion. Periodic voltage disturbance caused by the normal operation of power electronics devices when current is commutated from one phase to another.

- **Noise:** Noise is unwanted electrical signals with broadband spectral content lower than 200 kHz superimposed upon the power system voltage or current in phase conductors, or found on neutral conductors or signal lines. Noise in power systems can be power electronic devices, control circuits, arcing equipment, loads with solid-state rectifiers, and switching power supplies. Improper grounding often exacerbates noise problems.

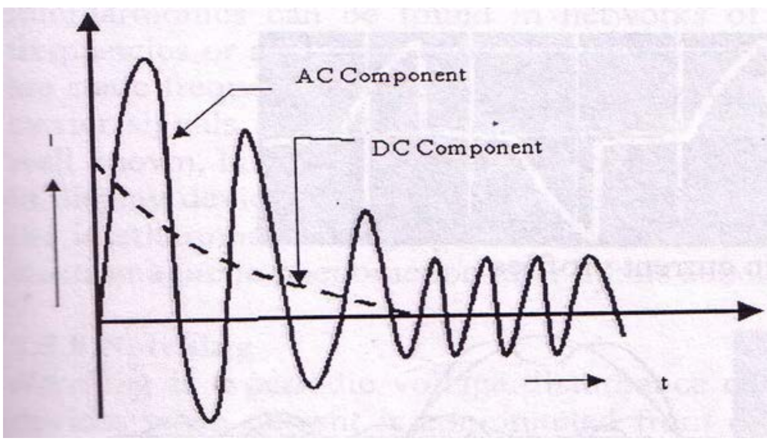


Figure 6. Appearance of DC during fault condition.

Table 1. Threshold Values used in the Survey [4]

| Power Quality Parameter | Threshold Value |
|---|---|
| Normal Voltage | 11kV |
| Frequency | 50Hz |
| Over Voltage | ≥11.55 kV (+5%) |
| Under Voltage | ≤ 10.45 kV (-5%) |
| Swell | ≥13.2 kV (+20%) |
| Sag | ≤ 8.8 kV (-20%) |
| Outtage | ≤ 1.1 kV (-90%) |

Table 2. Categories and typical characteristics of power system disturbances

| Categories | Typical spectral content | Typical duration | Typical voltage magnitude |
|---|---|---|---|
| *Transients* | | | |
| Impulsive | | | |
| Nanosecond | 5µs rise | < 50 ns | |
| Microsecond | 1 µs rise | 50 ns- 1 ms | |
| Millisecond | 0.1 ms rise | > 1 ms | |
| Oscillatory | | | |
| Low frequency | < 5 kHZ | 0.3-50 ms | 0-4pu |
| Medium frequency | 5-500 kHz | 20 µs | 0-8pu |
| High frequency | 0.5-5 MHz | 5 µs | 0-4pu |
| *Short duration variations* | | | |
| Instantaneous | | | |
| Sag | | 0.5-30 cycles | 0.1-0.9pu |
| Swell | | 0.5-30 cycles | 1.1-1.8pu |
| Momentary | | | |
| Interruption | | 0.5 cycles – 3 s | < 0.1pu |
| Sag | | 30 cycles – 3 s | 0.1-0.9pu |
| Swell | | 30 cycles – 3 s | 1.1-1.4pu |
| Temporary | | | |
| Interruption | | 3 s-1 min | < 0.1pu |
| Sag | | 3 s-1 min | 0.1-0.9pu |
| Swell | | 3 s-1 min | 1.1-1.2pu |
| *Long duration variations* | | | |
| Interruption, sustained | | > 1 min | 0.0pu |
| Under voltages | | > 1 min | 0.8-0.9pu |

| | | | |
|---|---|---|---|
| Over voltages | | > 1 min | 1.1-1.2pu |
| *Voltage imbalance* | | Steady state | 0.5-2% |
| *Waveform distortion* | | | |
| DC offset | | Steady state | 0-0.1% |
| Harmonics | $0\text{-}100^{th}$ | Steady state | 0-20% |
| Interharmonics | 0-6 kHz | Steady state | 0-2% |
| Notching | | Steady state | |
| Noise | Broad band | Steady state | 0.1% |
| *Voltage fluctuations* | < 25 Hz | Intermittent | 0.1-7% |
| *Power frequency variations* | | < 10 s | |

## Irritant Power System Disturbance

**Voltage Sags or Dips:** Voltage sags are generally created on the electric system when faults occur due to the overloading, lightning, accidental shorting of the phases by stress, animals, birds, human error such as digging under ground lines or auto mobiles hitting electric poles and failure of electrical equipment. Sags also can occur when large motor loads are started, or due to the operation of certain types of electrical equipment such as welders, arc furnaces, smelters etc.

Typical examples of sags due to overloading or short circuits are shown in Figure 7, 8 and 9. Like sags brownouts can cause temporary low line voltage, shutdowns, loss of microprocessor memory, loss of control, overheating of motors, insulation breakdown, protective device tripping, speed variation, reduced motor torques which can lead to stalling, increased maintenance and downtime and increased overall operating expenses.

Voltage dips are short-duration reductions in r.m.s. voltage caused by short-duration increases of the current, typically at another location than where the voltage dip is measured. The most common causes of over currents leading to voltage dips are motor starting, transformer energizing and faults. Also capacitor energizing and switching of electronic load lead to short duration over currents, but the duration of the over current is too short to cause a significant reduction in the r.m.s. voltage. These events are normally not referred to as voltage dips but as voltage notches or voltage transients. Voltage dips due to short circuit and earth faults are the cause of the vast majority of equipment problems. Most of the recent emphasis on voltage dips is directed towards these fault-related dips. An example of a measured voltage dip is shown in Figure 10, where the three voltage waveforms are given.

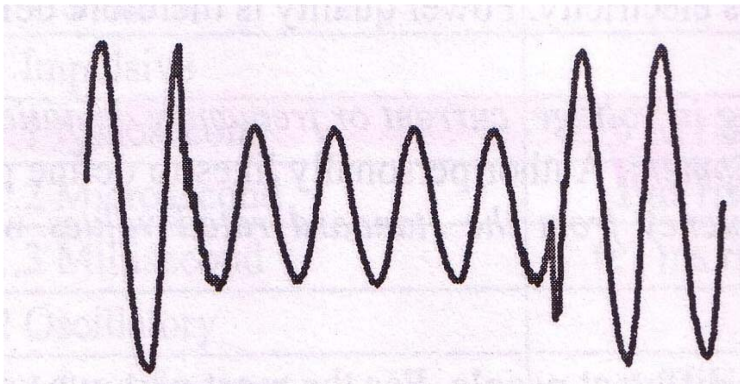

Figure 7. Overloading induced voltage sag.

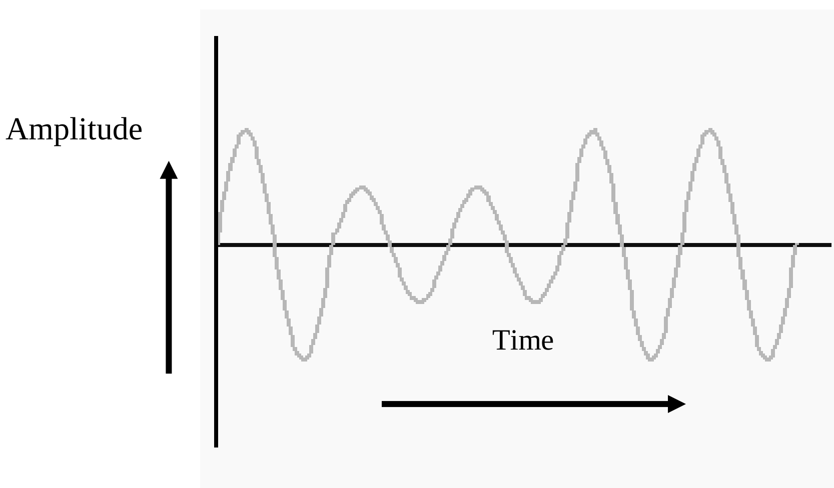


Figure 8. Motor starting induced voltage dip.

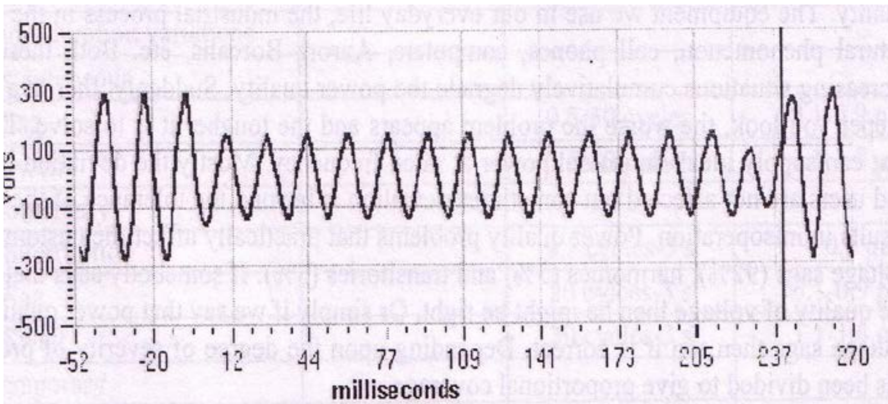


Figure 9. Single Line Ground Fault induced voltage dip.

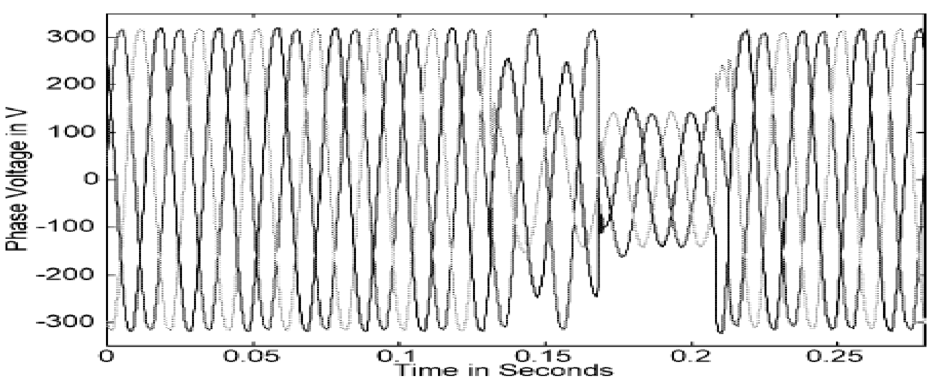


Figure 10. Typical example of a voltage dip.

**Swells:** During sags or by some operational reasons of certain types of equipment temporary over voltage condition, which is called, swell, as defined may occur during routine operation. Examples of swell are given below.

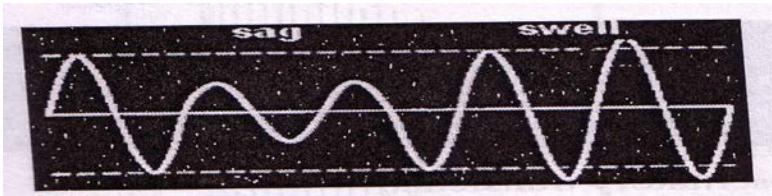


Figure 11. Swells after sag.

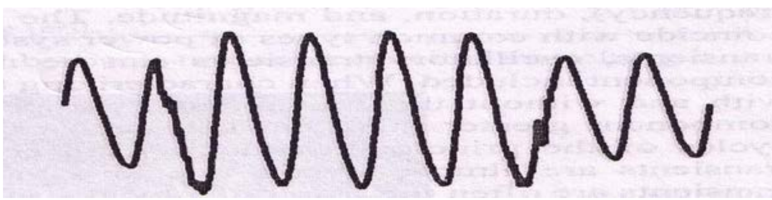

Figure 12. Example of typical swell.

*Voltage Dip Mitigation Methods*

What has to be mitigated here is the tripping of equipment due to voltage dips. This can be done in a number of ways:

- Reducing the number of faults: There are several wellknown methods for this like tree-trimming, animal guards, and shielding wires, but also replacing overhead lines by underground cables. As most of the severe dips are due to faults, this will directly affect the dip frequency.

- Faster fault clearing: This requires improved protection techniques. Much gain can be obtained in distribution networks, but at transmission level the fault-clearing time is already very short. Further improvement at transmission level would require the development of a new generation of circuit breakers and relays.

- Improved network design and operation: The network can be changed such that a fault will not lead to a severe dip at a certain location. This has been a common practice in the design of industrial power systems, but not in the public supply. Possible options are to remove long overhead feeders from busses supplying sensitive customers, and connecting on-site generators at strategic locations. Also the use of very fast transfer switches can be seen as a network-based solution.

- Mitigation equipment at the interface: The most commonly used method of mitigating voltage dips is connecting a UPS or a constant-voltage transformer between the system and the sensitive load. For large loads the static series compensator of DVR (dynamic voltage restorer) is a possible solution.

- Improved end-user equipment: Making the equipment immune against all voltage dips would also solve the problem, but it is for most equipment not (yet) feasible.

The ongoing discussion on voltage-dip mitigation concerns the responsibility sharing between the customer and network: should the solution be sought in the network or with the customer. In some cases the costs of mitigation equipment are shared or power quality contracts define the responsibility. In the long run an agreement has to be reached between what are ‘normal dips’ and what are ‘abnormal dips’. For normal dips end-user equipment is expected to be immune, whereas abnormal dips should have a small frequency of occurrence, see Figure 13.

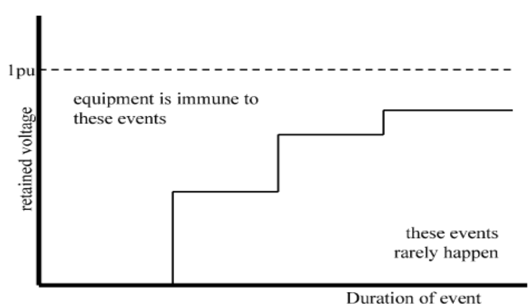


Figure 13. Distinction between events that are responsibility of the customer and those that are responsibility of the network operator.

## Who Needs Power Quality Study?

Power quality study is needed by the industries whose equipment malfunctions repeatedly resulting in production and economic losses. If the equipment works as planned, whatever is the quality of utility supply, there is no need to conduct power quality study. Power quality studies are often carried out by consultants to settle quarrels between utility and large industrial customers or by independent power quality experts for utilities.

Power quality engineer behaves like a judge and decides on the basis of data recorded by utility and customers. A good power quality engineer always establishes a relation between power quality data and events occurred on the utility and customer network at that time. The quarrels are very interesting when many large industrial customers are connected to the same network. Power quality is the study of interesting stories. The stories become even more interesting when technician staff on duty writes the cause of problem using their own definitions and terms.

To understand the power quality study procedures the first step is data collection. The primary sources of data are the technicians who spend most of their time near that equipment. It will be useful to state some stories to enable the readers to develop necessary skill how to obtain basic information on cause problem from layman staff where sensitive recorders are not available.

## CONCLUSION

The following conclusions could be made from the review work of power quality concerns based on the above description.

- In order to have a clear picture of the power quality level in the system, it is necessary to have reliable and organized data collection devices, capable of interfacing with personal computers (PC). For this reason, small HHUs (Hand held units) were used to download data from the monitoring devices.

- Power quality is a very wide and dispersed area that somehow accidentally became viewed as one subject. Voltage dips presented in this paper shown the variety of aspects related to disturbances. Other disturbances that would deserve an equal amount of attention are (long and short) interruptions, transients, and high-frequency waveform distortion.

- However, it is a serious misconception that power quality is a very technical area and the engineer must be highly trained to understand the problems. It requires expensive equipment that is very delicate and sensitive requiring yearly calibration and quality is something that one alone can't control over. The technical team can take what the facility/utility gives to the system room and the team has to tolerate it. It's out of team's control! The team don't have the time, money or resources to worry about to establish the cause of problem but the expertise exist to sort it out.

- One must have a PQ monitoring system so as to easily detect faults in the power system and received a page informing that the voltage sag occurred on the motor circuit serving the conveyor line at 1:30p.m., stopping production for 15 sec.

- Finally in this paper, there is no way to write presentable material on electric power quality without consulting the standard published data. The readers are advised to consult references given at the end for detailed in depth study of this power quality concerns. It is believed that no reader can make full use of present work on power quality issued and their solutions, only by reading this paper, without attending regular lectures or having significant field experience of a utility or industry.

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