International Journal of Electrical and
Electronics Engineering (IJEEE)
Vol.1, Issue 1 Aug 2012 83-91

International Academy of Science, Engineering and Technology
Connecting Researchers; Nurturing Innovations

POWER QUALITY: PROBLEMS, EFFECTS AND ECONOMIC IMPACTS

S. GUPTA

Electrical-Engg. Deptt, N.I.T. Raipur, India

ABSTRACT

Modern customers use large number of sensitive devices quite sensitive to Power-Quality (PQ) disturbances in the supply network. Poor PQ may have significant economic impacts on the operation of many different types of facilities. The costs of PQ problems are highly dependent of several factors.

This paper presents different power quality problems, their effects on different equipments, power systems and ultimate economic impacts.

KEYWORDS: Economic Impacts**,** Power-Quality**,** Sensitive Devices.

INTRODUCTION

Earlier, the main concern of consumers of electricity was the reliability of supply, which is nothing but the continuity of electric supply. However, these days it is not only reliability, the consumer wants; quality of power too is very important to them. In several processes such as Semiconductor manufacturing or Food processing plants, a voltage dip of very short duration can cost them a substantial amount of money [1]. Even these short dips of voltage are sufficient to cause conductors on motor drives to drop out from system. Stoppage in a portion of a process can destroy the condition for quality control of the product and require restarting of production. Thus in this changed scenario in which the whole system increasingly demand quality power, the term POWER QUALITY (PQ) attains increased significance [2].

INTEREST IN POWER-QUALITY (PQ)

The fact that PQ has become an issue recently does not mean that it was not important in past. All over the world utilities have worked on the improvement of power quality for decades [3, 4]. Even the term Power-Quality has been in use for a rather long time already.

The ideal ac line supply, by the utility system should be a pure sine wave of fundamental frequency (50/60Hz). In addition, peak of the voltage should be of rated value. Unfortunately the ac line supply that we actually receive not only contains power frequency components but also so-called harmonic components with frequencies equal to a multiple of the power frequency. Equipments have been introducing harmonic distortion since last many decades, but recently the amount of load, fed via power electronic converters has increased enormously, causing more harmonic voltage distortion. Each individual device does not generate much harmonic current but all of them together cause a serious distortion of the supply voltage [5, 6].

Definition

As per IEEE standard 1100: Power quality is the concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment. The international standard setting organization in electrical engg. (IEC) does not yet use the term power quality in any of its standard documents. Instead they use the term Electromagnetic-Compatibility (EMC), defined as the ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. Recently the IEC has also started a project group on power quality [7]. For describing the scope of the project group power quality was defined as: Set of parameters defining the properties of the power quality as delivered to the user in normal operating conditions in terms of continuity of supply and characteristics of voltage (symmetry, frequency, magnitude, waveform etc.).

The causes

The causes of power quality deteriorating problems are generally complex and difficult to detect. Customers often describe tripping of equipments due to disturbances in the supply voltage as ‘bad power quality’. On the other side, utility often view disturbances due to end users equipments as the main power quality problem.

Modern power electronic equipments are not only sensitive to voltage disturbances; they also cause disturbances to other customers. The increased use of converter driven equipment has led to a large growth of voltage disturbances [8].

There are two different categories of causes for deterioration in power quality [9]

Natural Causes

1. Faults or lighting strikes on transmission lines or distribution feeders.
2. Falling of trees or branches on distribution feeders during stormy conditions
3. Equipment failure.

Man Made Causes

1. Transformer energization, capacitor or feeder switching.
2. Power electronic loads such as UPS, ASD, converters etc.
3. Arc furnaces and induction heating systems
4. Switching on or off of large loads.

Various power quality problems and their details [10, 11] have been listed in Table Ias:

Table 1: Power Quality Problems and their Causes

Broad Categories	Specific categories	Method of characterization	Typical causes
Transients	Impulsive	Peak magnitude, rise time and duration	Lightning strike, transformer energization, capacitor switching
	Oscillatory	Peak magnitude, frequency component	Line or capacitor or load switching
Short duration voltage variation	Sag	Magnitude, duration	Ferroresonant transformer, SLG fault
	Swell	Magnitude, duration	Ferro resonant transformer, S-L-G fault
	Interruption	Duration	Temporary (self-clearing) faults
Long duration voltage variation	Undervoltage	Magnitude, duration	Switching on loads, capacitor deenergization
	Overvoltage	Magnitude, duration	Switching off loads, capacitor energization
	Sustained Interruption	Duration	Faults
Voltage imbalance		Symmetrical components	Single-phase loads, Single-phasing condition
Waveform distortion	Harmonics	THD, Harmonic spectrum	ASD and other nonlinear loads
	Notching	THD, Harmonic spectrum	Power electronic converter
	DC offset	Volts, amps	Geomagnetic disturbance, half-wave rectification
Voltage flicker		Frequency of occurrence, modulating Frequency	Arc furnace, arc lamps

Impulsive transient does not travel very far from their point of entry, but can give rise to an oscillatory transient, which lead to transients over voltage and consequent damage to the power line

Insulators. Impulsive transients are usually suppressed by surge arrestors. Single-Line-Ground faults on the utility distribution or transmission system are often the cause of voltage sags (dips). Voltage sags can trip a motor or cause its controller to malfunction so as to cause loss of production. It can also force a computer system or data processing system to crash, which can be prevented by an Uninterruptible Power Supply (UPS), but it in turn generate harmonics [12, 13,14,15].

During voltage swell, the protective circuit of an Adjustable Speed Drive (ASD) can trip the system. The lives of computer and many home appliances may be shortened by the stress put on them. A temporary interruption lasting a few seconds will cause loss of production, erasing of computer data etc. During peak hours it may cost much amount.

The long duration voltage variation has greater impact than short duration voltage variation. A sustained over voltage lasting for few hours can cause damage to household appliances. The under voltage has the same effect as that of voltage sag. The termination of process is sudden in sag and normal operation can be resumed after the normal voltage is restored. However in case of sustained under voltage, the process cannot be even restarted or resumed. A sustained interruption is usually caused by faults.

Voltage imbalance can cause temperature rise in motors and even cause a large motor to trip.

Harmonics, DC offset and Notching cause waveform distortions. Harmonics are the periodic disturbances in voltage and current. They can be integer multiple of fundamental frequency, fraction of the fundamental frequency (sub harmonics) and at frequencies that are not integer multiple of fundamental frequency (interharmonics). Unwanted harmonic currents flowing through the network (system) can cause needless losses. Harmonics can also cause malfunction of ripple control or traffic control systems, losses and heating in transformers, electromagnetic interference (EMI) and interference with the communication systems. Ripple control refers to the use of a 300 to 2500Hz signal added to distribution lines to control switching of loads such as hot water heaters or street lighting. Interharmonic voltages can upset the operation of fluorescent lamps and television receivers. They can also produce acoustic noise in power equipment. DC offsets can cause saturation in the power transformer magnetic circuits. A notch is a periodic transient that rids on the supply voltage. Because of high rate of rise of voltage at the notches, it can damage capacitive components connected in shunt [16, 17, 18, 19, 20].

Voltage flickers are frequent variations in voltage that can cause the light intensity from incandescent lamps to vary. This can have adverse effects on human health as the high frequency flickering of light bulbs; fluorescent tubes or television screen can cause strain on the eyes resulting in headaches or migraine. The voltage flickering can also reduce the life span of electronic equipment, lamps etc. [21].

Thus the lack of standard quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained.

It is clear from the previous text and Table1 that the majority of events currently of interest are associated with either a reduction or an increase in the voltage magnitude. A straightforward classification is given in Table II.

Table 2: Suggested Classifications of Voltage Magnitude Events

Event magnitude				
110%	Very short overvoltage	Short overvoltage	Long overvoltage	Very long overvoltage
	Normal operating voltage			
90%	Very short undervoltage	Short undervoltage	Long undervoltage	Very long undervoltage
1-10%	Very short interruption.	Short interruption	Long interruption	Very long interruption.
Event duration	1-3 cycles		1-3 min	1-3 hours

The voltage magnitude is split into three regions:

Interruption: the voltage magnitude is zero

Undervoltage: the voltage magnitude is below its normal value

Overvoltage: the voltage magnitude is above its normal value

In duration, a distinction is made between

- **Very Short :** corresponding to transient and self-restoring events**;**
- **Short :** corresponding to automatic restoration of the pre-event situation**;**
- **Long :** corresponding to manual restoration of the pre-event situation**;**
- **Very Long :** corresponding to repair or replacement of faulted components.

Power Outages

The most common cause of an outage is equipment or component failure, e.g. loss of a generator, Transformer or feeder due to faults. Some times utilities have scheduled outages to maintain the power equipment, which involves changing of transformer oil, replacement of a section of feeder conductors or changing of old, and faulty switchgear or other equipment. During scheduled outages, a power distribution company may be able to cater to the large majority of the customers by channeling power through alternate feeders or supply transformers wherever available, but this may not be always possible. Such scheduled outages occur only occasionally and usually prior notice is given to customers those are affected by the outages.

It is the unscheduled outages that cause major problems to both utilities and customers alike. These cause higher financial loss to the customers. The impact of even short outages in semiconductor plants can be very severe, so such outages must be minimized. Amongst the unscheduled outages, natural disasters and accidents like earth quakes, floods, blizzards tornadoes fires, arsons, terrorist activities etc cause some. Even if some of these causes can be predicted, it is rather difficult to entirely prevent their impact on the power system.

To define the response of the system to the outages, there are various reliability indices [22]:

SAIFI (System Average Interruption Frequency Index)

Is the total no. of customer interruption events that have occurred over a period of time (usually one year) divided by the total number of customers i.e. it gives average interruption per customer over a year

$$\text{SAIFI} = \frac{\text{Total number of customer interruptions}}{\text{Total number of customers in the system}}$$

CAIFI (Customer Average Interruption Frequency Index)

$$\text{CAIFI} = \frac{\text{Number of customer interruptions}}{\text{Number of customers who had at least one interruption}}$$

The index SAIFI gives the average interruptions per customer, but all customers in the system may not face an equal amount of interruptions, so we use CAIFI, which normalizes the number of interruptions w.r. to the total no. of customers facing interruptions. Numerical value of CAIFI will be greater than or at the most equal to that of SAIFI. Thus a comparison of these two indices can give us an insight in to the system.

SAIDI (System Average Interruption Duration Index)

Gives the averages duration of all interruptions per customer i.e.

$$\text{SAIDI} = \frac{\text{Sum total of the duration of all customer interruptions}}{\text{Total number of customers in the system}}$$

CAIDI (Customer Average Interruption Duration Index)

The total interruption duration over a year is averaged amongst the customers, who had at least one interruption i.e.

$$\text{CAIDI} = \frac{\text{Sum total of duration of all customers interruption}}{\text{Number of customers with at least one interruption}}$$

As in the case of SAIFI and CAIFI, a large difference between SAIDI and CAIDI indicate that the outages are connected on a limited set of customers and hence further investigation will be required.

MAIFI (Momentary Average Interruption Frequency Index)

This index deals with momentary or short duration interruptions. In general the utilities do not treat the short duration interruptions as outages and hence momentary interruptions are not classified under SAIDI or CAIFI

$$\text{MAIFI} = \frac{\text{Total number of customer momentary Interruptions}}{\text{Total number of customers}}$$

The frequency indices tell us how often faults occur, giving an indication about system equipment and network layout. Where as duration indices are functions of the organization ability of the utility to limit the faulted section to the smallest number of customers and the ability to control the repair time.

Economic Impacts of Power Quality

The cost related to a PQ disturbance can be divided in

i) Direct costs: the cost that can be directly attributed to the disturbance. Include the damage n the equipment, loss of production, loss of raw material, restart cost etc.

ii) Indirect costs: These costs are very hard to evaluate. Investments to prevent PQ problems may be considered an indirect cost.

iii) Non material inconvenience: some inconvenience due to power disturbance cannot be expressed in money, such as not listening to the radio or not watching TV. The only way to account is to establish an amount of money that the consumer is willing to pay to avoid this inconvenience.

The cost associated with power outages can be tremendous. Manufacturing facilities have costs ranging from Rs.4, 00,000 to millions of rupees associated with a single interruption to the process. Momentary interruptions or voltages sags lasting less than 100 ms can have the same impact as in outage lasting many minutes. If an interruption costs Rs.16, 00,000, the total costs associated with voltage sags and interruptions would be Rs.2, 70, 40,000/-year. (The total cost is appro. 17 times the cost of an interruption) [23].

According to Contingency Planning Research Company's annual study, downtime caused by power disturbance results in major financial losses. Here are a few examples of the ***hourly losses*** experienced by a few businesses:

- Airline reservation centers: Rs.33,50,000 – Rs.55,60,000

- ATM network and service fees: Rs 6,00,000 - Rs 8,50,000
- Brokerage (retail): Rs 280 – Rs 365 million
- Credit card sales authorizations: Rs 110 – Rs 155 million
- Telephone ticket sales: Rs 28, 00,000 – Rs 41, 00,000
- Catalog sales centers (large retailers): Rs 30,00,000 - Rs 60,00,000.

CONCLUSIONS

This report contains the Overview of Power- Quality and problems related to Power- Quality. Estimation of financial losses for a customer because pf poor PQ is quite complicated as it includes various direct (immediately visible costs) and indirect (long term) costs. Several studies have been made to evaluate the costs of PQ problems for consumers. The assessment of an accurate value is nearly impossible; so all the studies are based on estimates.

REFERENCES

1. P.Zanchetta et al, "New power quality assessment criteria for supply systems under unbalanced and nonsinusoidal conditions", IEEE trans.on Power Delivery, vol.19, no.3, July.2004pp1284-1290.
2. R.C.Dugan et al, 'Electrical power system quality', NewYork Mc-graw-Hill, 1996.
3. M.Morcos et al, "Electric power quality and artificial intelligence: Overview and applicability" , IEEE Power engineering review, vol.19, no.6, Jun.'99, pp5-10.
4 Wael R. "A power quality perspective to system operational diagnosis using fuzzy logic and adaptive technique", IEEE trans.on Power Delivery, vol.18, no.3, July2003, pp903-909.
5. M.H.J.Bollen, "Fast assessment method for voltage sag in distribution system", IEEE trans.on I*ndustry application*, Nov/Dec'96, vol.32, no.6, pp1414-1423.
6. "Detection and classification of PQ problems", Proc. of IWANN'05, 8th international work-conference on artificial neural network.
7. F.Martzloff, "Power quality work at the international Electrotechnical Commission,PQA97",Europe, June 1997, Stockholm, Sweden.
8. Math H.J.Boolen, 'Understanding power quality problems: voltage sag and interruptions', IEEE press, 2001.
9. S.D.Kim et al, "An improved method for classifying power quality Disturbances: Electric power components and systems (Taylor and Francis series), vol32, no.4, April2004, pp407-420.
10. S.H.Jaramillo et al, "Power quality indices for a periodic voltages and currents", IEEE trans.on Power Delivery, vol.15, no.2, april.2000, pp784-789.

11. A. Ghosh et al, 'Power quality enhancement using custom power Devices', Kluwer Academic Pub. Bostom, 2000.
12. Tien-ting Chang et al, “An efficient approach for reducing harmonic voltage distortion in distribution system with active line conditioners”, IEEE trans.on Power Delivery, vol.15, no.3, July.2000, pp990-995.
13. Hussain A. et al, “Automatic detection of power quality disturbances and identification of transient signals”, 6th international symposium 2001 on signal processing and its applications (13-16 Aug), vol.2, pp462-465&952-958.
14. J.Arrillaga et al, “A modular approach to the solution of 3-phase harmonic power flow”, IEEE trans.on Power Delivery, vol.15, no.3, July 2000, p984.
15. T.A.Short, ‘Distribution Reliability and Power Quality’, Taylor and Francis group, Boca Raton, London, NewYork, 2006.
16. P.K.Rout et al, “Effects of harmonic disturbances on electrical equipments”, Jour. of Electrical India, July 2005, pp48-54.
17. G.T.Heydt et al, “Second harmonic components in power system voltage and currents”, IEEE trans.on Power Delivery, vol.20, no.1, Jan.2005 pp521-523.
18. Aielo M. et al, “A self synchronizing instrument for harmonic source detection in power system”, IEEE trans. On Instrumentation and measurement, Feb’05, vol.54, issue 1.
19. W. Mack Grady et al, “Understanding power system harmonics “, IEEE Journal on Power engineering review, vol.21, no.11, Nov.2001, pp8-11.
20. Hermann W. Dommel et al, “A multiphase harmonic load flow solution technique”, IEEE trans.on Power System, vol.6, no.1, Feb.’91, pp174-180.
21. J. Pedra et al, “Effects of balanced and unbalanced voltage sags on VSI-fed ASD”, IEEE trans.on Power Delivery, vol.20, no.1, Jan.2005pp224-233.
22. H.L.Lewis, Power distribution planning reference book, Marcel Dekker Newyork, 1997.
23. M.Mc Granaghan et al, “Economic evaluation of power quality”, IEEE Power engineering review, Vol.22, no.2, Feb.2002, pp8-12.