

## Chapter 2

# Electric Power Quality

**Abstract** The chapter starts with an introduction of power quality. Different aspects are then discussed to define electric power quality. Different sub-branches in power quality study are discussed. After this, disturbances normally occurred in power system are discussed. Short definitions of these power system disturbances are presented. Power quality related problems are summarized. Different guidelines given by IEC, IEEE, etc. are presented in tabular form.

### 2.1 Introduction

Development of technology in all its areas is progressing at a faster rate. Power scenario has changed a lot. With the increase of size and capacity, power systems have become complex leading to reduced reliability. But, the development of electronics, electrical device and appliances have become more and more sophisticated and they demand uninterrupted and conditioned power. These have pushed the present complex electricity network and market in a strong competition resulting in the concept of deregulation. In this ever changing power scenario, quality assurance of electric power has also been affected. It demands a deep research and study on the subject 'Electric Power Quality'.

### 2.2 Electric Power Quality

Electric Power Quality (EPQ) is a term that refers to maintaining the near sinusoidal waveform of power distribution bus voltages and currents at rated magnitude and frequency. Thus EPQ is often used to express voltage quality, current quality, reliability of service, quality of power supply, etc.

EPQ has captured increasing attention in power engineering in recent years. In the study of EPQ, different branches are being formed. They deal with different issues related to power quality. Study on electric power quality may be divided into following stages [1–15]:

1. Fundamental concepts
2. Sources
3. Effects
4. Modeling and Analysis
5. Instrumentation
6. Solutions

All branches are inter-related and very much depended on each other. ‘Fundamental concept’ of EPQ, identifies the parameters and their degree of variation with respect to their rated magnitude which are the base reason for degradation of quality of electric power. ‘Sources’ are the regions or locations or events which causes the unwanted variation of those parameters. It’s really a big challenge to the power engineers to find out the exact sources of power quality related disturbance in the ever increasing complex network. ‘Effects’ of poor quality of power are the effects faced by the system and consumer equipment after the occurrence of different disturbances. In ‘modeling and analysis’, attempts are taken to configure the disturbance, its occurrence, sources and effect; mainly based on the mathematical background. For monitoring of EPQ, constant measurement and ‘instrumentation’ of the electric parameters are necessary. Complete solution, i.e. delivery of pure power to the consumer side is practically impossible. Our target is to minimize the probability of occurrence of disturbances and to reduce the effects of EPQ problems.

EPQ describes the variation of voltage, current and frequency in a power system. Most power system equipment has been able to operate successfully with relatively wide variations of these three parameters. However, within the last five to fifteen years, a large amount of equipment has been added to the power system, which is not so tolerant of these variations. The sophistication of electrical appliances with the development of electronics has added to the demand of quality power at the consumer premises. To ensure uninterrupted and quality power has thus become a point of competition for the power producers. Thus an open and competitive power market has paved its way. These situations have introduced the concept of deregulation in power sector. Like all other commodities, for electric power there should be quality issues at each physical location in all system especially in deregulated system.

Poor power quality sources can be divided in two groups: (1) actual loads, equipment and components and (2) subsystems of transmission and distribution systems. Quality degradation of electric power is mainly occurred due to power line disturbances such as impulses, notches, voltage sag and swell, voltage and current unbalances, momentary interruption and harmonic distortions, different standards and guidelines of which are mentioned in the International Electro-technical Commission (IEC) classification of power quality and relevant IEEE standard. The other major contributors to poor power quality are harmonics and reactive power. Solid state control of ac power using high speed switches are the main source of harmonics whereas different non-linear loads contribute to excessive drawl of reactive power from supply.

## 2.3 Classification of Power System Disturbances

Power quality problems occur due to various types of electrical disturbances. Most of the EPQ disturbances depend on amplitude or frequency or on both frequency and amplitude. Based on the duration of existence of EPQ disturbances, events can be divided into short, medium or long type. The disturbances causing power quality degradation arising in a power system and their classification mainly include:

1. **Interruption/under voltage/over voltage:** these are very common type disturbances. During power interruption, voltage level of a particular bus goes down to zero. The interruption may occur for short or medium or long period. Under voltage and over voltage are fall and rise of voltage levels of a particular bus with respect to standard bus voltage. Sometimes under and over voltages of little percentage is allowable; but when they cross the limit of desired voltage level, they are treated as disturbances. Such disturbances are increasing the amount of reactive power drawn or deliver by a system, insulation problems and voltage stability.
2. **Voltage/Current unbalance:** voltage and current unbalance may occur due to the unbalance in drop in the generating system or transmission system and unbalanced loading. During unbalance, negative sequence components appear. It hampers system performance may change loss and in some cases it may hamper voltage stability.
3. **Harmonics:** harmonics are the alternating components having frequencies other than fundamental present in voltage and current signals. There are various reasons for harmonics generation like non linearity, excessive use of semiconductor based switching devices, different design constraints, etc. Harmonics have adverse effects on generation, transmission and distribution system as well as on consumer equipments also. Harmonics are classified as integer harmonics, sub harmonics and inter harmonics. Integer harmonics have frequencies which are integer multiple of fundamental frequency, sub harmonics have frequencies which are smaller than fundamental frequency and inter harmonics have frequencies which are greater than fundamental frequencies. Among these entire harmonics integer and inter harmonics are very common in power system. Occurrence of sub harmonics is comparatively smaller than others. Sometimes harmonics are classified: time harmonics and spatial (space) harmonics. Obviously their causes of occurrence are different. Harmonics are in general are not welcome and desirable. Harmonics are assessed with respect to fundamental. Monitoring of harmonics with respect to fundamental is important consideration in power system application. For this purpose different distortion factor with respect to the fundamental have been introduced.
4. **Transients:** transients [16, 17] may generate in the system itself or may come from the other system. Transients are classified into two categories: dc transient and ac transient. AC transients are further divided into two categories: single cycle and multiple cycles.

**Table 2.1** Definition of power system disturbances

Sl No	Disturbance	Short definition
A	Interruption	voltage magnitude is zero
	Under voltage	voltage magnitude is below its nominal value
	Over voltage	voltage magnitude is above its nominal value
B	<i>Voltage sag</i>	A reduction in RMS voltage over a range of 0.1–0.9 pu for a duration greater than 10 ms but less than 1 s
C	<i>Voltage swell</i>	An increase in RMS voltage over a range of 1.1–1.8 pu for a duration greater than 10 ms but less than 1 s
D	<i>Flicker</i>	A visual effect of frequency variation of voltage in a system
E	<i>Voltage/Current unbalance</i>	Deviation in magnitude of voltage/current of any one or two of the three phases
F	<i>Ringing waves</i>	A transient condition which decays gradually
G	<i>Outage</i>	Power interruption for not exceeding 60 s duration due to fault or maltripping of switchgear/system
H	Transients	Sudden rise of signal
I	Harmonics	Non-sinusoidal wave forms

5. ***Voltage sag***: it is a short duration disturbance [18]. During voltage sag, r. m. s. voltage falls to a very low level for short period of time.
6. ***Voltage swell***: it is a short duration disturbance. During voltage sag, r. m. s. voltage increases to a very high level for short period of time.
7. ***Flicker***: it is undesired variation of system frequency.
8. ***Ringing waves***: oscillatory disturbances of decaying magnitude for short period of time is known as ringing wave. It may be called a special type transient. The frequency of a flicker may or may not be same with the system frequency.
9. ***Outage***: it is special type of interruption where power cut has occurred for not more than 60 s.

Short definitions of the power system disturbances are summarized in Table 2.1 [16–30].

## 2.4 Power Quality Standards and Guidelines

Standards and guidelines have been given by different technical bodies like IEEE, ANSI, IEC, etc. Those guidelines are very helpful in EPQ study and practice. Some references related to EPQ with their main content are presented in Tables 2.2 and 2.3 [31–37].

**Table 2.2** IEEE and ANSI guidelines

IEEE 4	Standard techniques for high-voltage testing
IEEE 100	Standard dictionary of electrical and electronic engineering
IEEE 120	Master test guide for electrical measurements in power circuits
IEEE 141	Recommended practice for electric power distribution for industrial plants with effect of voltage disturbances on equipment within an industrial area
IEEE 142	Recommended practice for grounding of industrial and commercial power systems
IEEE 213	Standard procedure for measurement of conducted emissions in the range of 300 kHz–25 MHz from television and FM broadcast receivers to power lines
IEEE 241	Recommended practice for electric power systems in commercial buildings
IEEE 281	Standard service conditions for power system communication equipment
IEEE 299	Standard methods of measuring the effectiveness of electromagnetic shielding enclosures
IEEE 367	Recommended practice for determining the electric power station ground potential rise and induced voltage from a power fault
IEEE 376	Standard for the measurement of impulse strength and impulse bandwidth
IEEE 430	Standard procedures for the measurement of radio noise from overhead power lines and substations
IEEE 446	Recommended practice for emergency and standby systems for industrial and commercial applications (e.g., power acceptability curve, CBEMA curve)
IEEE 449	Standard for ferro resonance voltage regulators
IEEE 465	Test specifications for surge protective devices
IEEE 472	Event recorders
IEEE 473	Recommended practice for an electromagnetic site survey (10 kHz–10 GHz)
IEEE 493	Recommended practice for the design of reliable industrial and commercial power systems
IEEE 519	Recommended practice for harmonic control and reactive compensation of static power converters
IEEE 539	Standard definitions of terms relating to corona and field effects of overhead power lines
IEEE 859	Standard terms for reporting and analyzing outage occurrences and outage states of electrical transmission facilities
IEEE 944	Application and testing of uninterruptible power supplies for power generating stations
IEEE 998	Guides for direct lightning strike shielding of substations
IEEE 1048	Guides for protective grounding of power lines
IEEE 1057	Standards for digitizing waveform recorders
IEEE P1100	Recommended practice for powering and grounding sensitive electronic equipment in commercial and industrial power systems
IEEE 1159	Recommended practice on monitoring electric power quality. Categories of power system electromagnetic phenomena
IEEE 1250	Guides for service to equipment sensitive to momentary voltage disturbances
IEEE 1346	Recommended practice for evaluating electric power system compatibility with electronics process equipment
IEEE P1453	Flicker

**Table 2.2** (continued)

IEEE/ANSI 18	Standards for shunt power capacitors
IEEE/ANSI C37	Guides for surge withstand capability (SWC) tests
IEEE/ANSI C50	Harmonics and noise from synchronous machines
IEEE/ANSI C57.110	Recommended practice for establishing transformer capability when supplying no sinusoidal load currents
IEEE/ANSI C57.117	Guides for reporting failure data for power transformers and shunt reactors on electric utility power systems
IEEE/ANSI C62.45 (IEEE 587)	Recommended practice on surge voltage in low-voltage AC power circuits, including guides for lightning arresters applications
IEEE/ANSI C62.48	Guides on interactions between power system disturbances and surge protective devices
ANSI C84.1	American national standard for electric power systems and equipment voltage ratings (60 Hz)
ANSI 70	National electric code
ANSI 368	Telephone influence factor
ANSI 377	Spurious radio frequency emission from mobile communication equipment

**Table 2.3** IEC guidelines

IEC 38	Standard voltages
IEC 816	Guides on methods of measurement of short-duration transients on low-voltage power and signal lines. Equipment susceptible to transients
IEC 868	Flicker meter. Functional and design specifications
IEC 868-0	Flicker meter. Evaluation of flicker severity. Evaluates the severity of voltage fluctuation on the light flicker
IEC 1000-3-2	Electromagnetic compatibility Part 3: Limits Section 2: Limits for harmonic current emissions (equipment absorbed current <16 A per phase)
IEC 1000-3-6	Electromagnetic compatibility Part 3: Limits Section 6: Emission limits evaluation for perturbing loads connected to MV and HV networks
IEC 1000-4	Electromagnetic compatibility Part 4: Sampling and metering techniques
EN 50160	Voltage characteristics of electricity supplied by public distribution systems
EC/EN 60868	Flicker meter implementation
IEC 61000	Electromagnetic compatibility (EMC)

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