

# Matoshri College of Engineering & Research Centre, Nasik.

BE Electrical

Subject: Power Quality

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# Syllabus

## **Unit 01: Basics of power quality and standards (6 hrs)**

Introduction and importance of Power Quality, symptoms of poor power quality. Various power quality issues such as transients, short duration voltage variations, long duration voltage variations, voltage imbalance, voltage fluctuations, voltage flicker and waveform distortion. Relevant power quality standards such as IEEE 1159- 2009 and IEEE 519- 2014. Grounding and power quality issues.

# Importance of PQ

- 1. Newer-generation load equipment, with microprocessor-based controls and power electronic devices, is more sensitive to power quality variations than was equipment used in the past.
- 2. The increasing emphasis on overall power system efficiency has resulted in continued growth in the application of devices such as high-efficiency, adjustable-speed motor drives and shunt capacitors for power factor correction to reduce losses. This is resulting in increasing harmonic levels on power systems and has many people concerned about the future impact on system capabilities.
- 3. End users have an increased awareness of power quality issues. Utility customers are becoming better informed about such issues as interruptions, sags, and switching transients and are challenging the utilities to improve the quality of power delivered.
- 4. Many things are now interconnected in a network. Integrated processes mean that the failure of any component has much more important consequences.

# Introduction

- Terms and Definitions

## Power Quality:

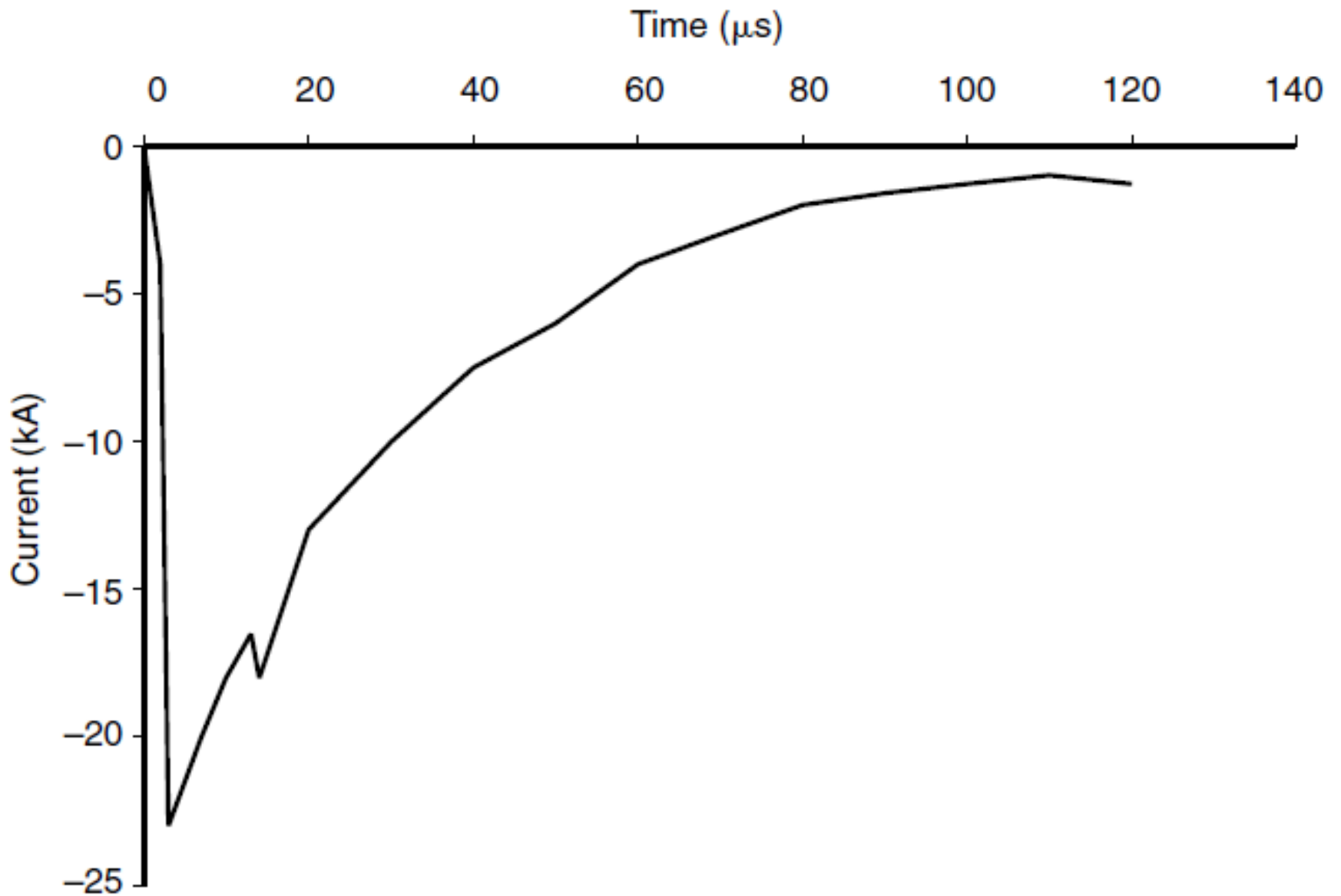
- **Power Quality = Voltage Quality**
- The power supply system can only control the quality of the voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in the power quality area are devoted to maintaining the supply voltage within certain limits.

# Transient

- The term *transients* has long been used in the analysis of power system variations to denote an event that is undesirable and momentary in nature.
- Transients can be classified into two categories,
  - *impulsive and oscillatory.*
- *These terms reflect the wave shape of a current or voltage transient.*

# Impulsive transient

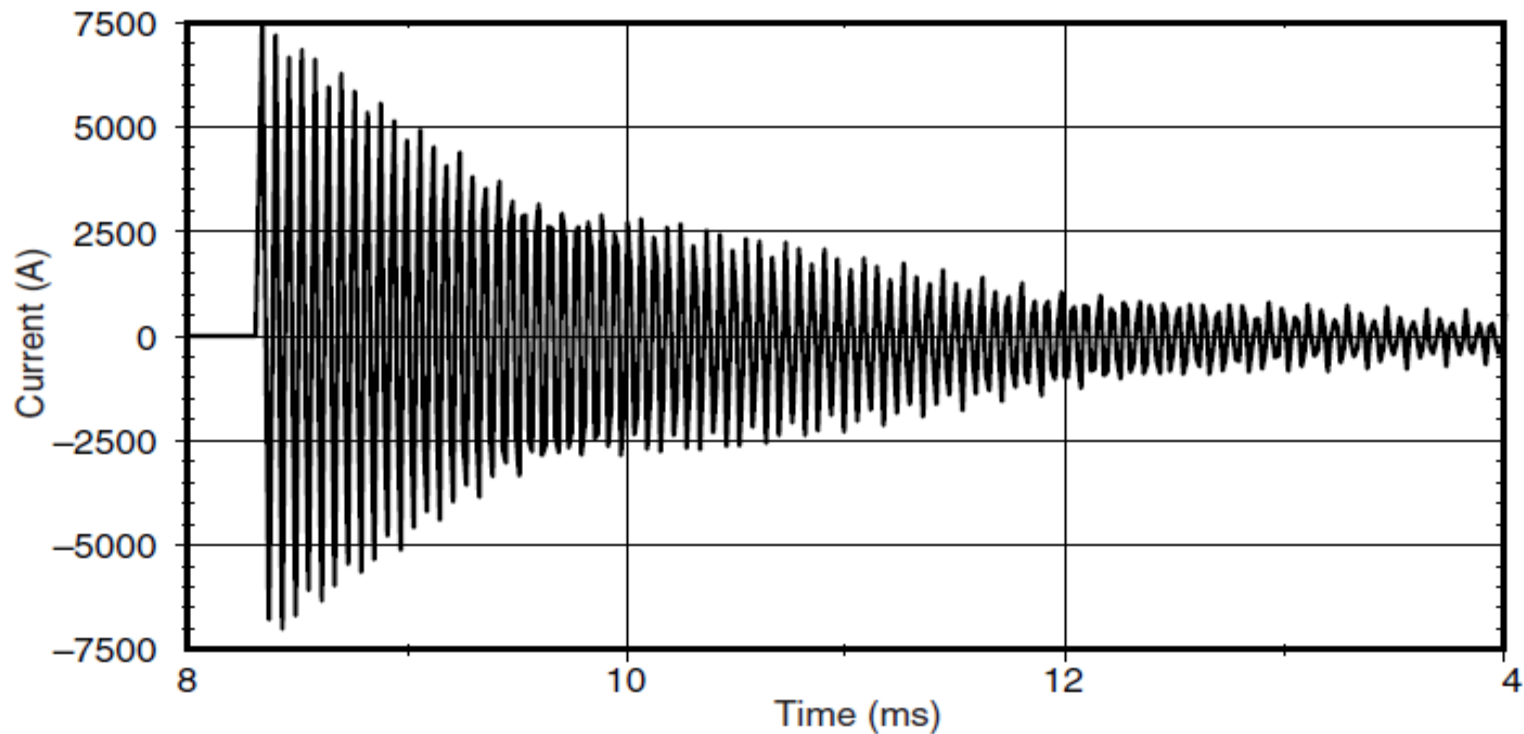
- *An impulsive transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity (primarily either positive or negative).*
- For example, a 1.2 x 50 $\mu$ s -2000-volt (V) impulsive transient nominally rises from zero to its peak value of 2000 V in 1.2  $\mu$ s and then decays to half its peak value in 50 s. The most common cause of impulsive transients is lightning.



| Lightning stroke current impulsive transient.

## Oscillatory transient

An oscillatory transient is a sudden, non-power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values.



**Figure 2.2** Oscillatory transient current caused by back-to-back capacitor switching.

A transient with a primary frequency component between 5 and 500 kHz with duration measured in the tens of microseconds (or several cycles of the principal frequency) is termed a *medium-frequency transient*.

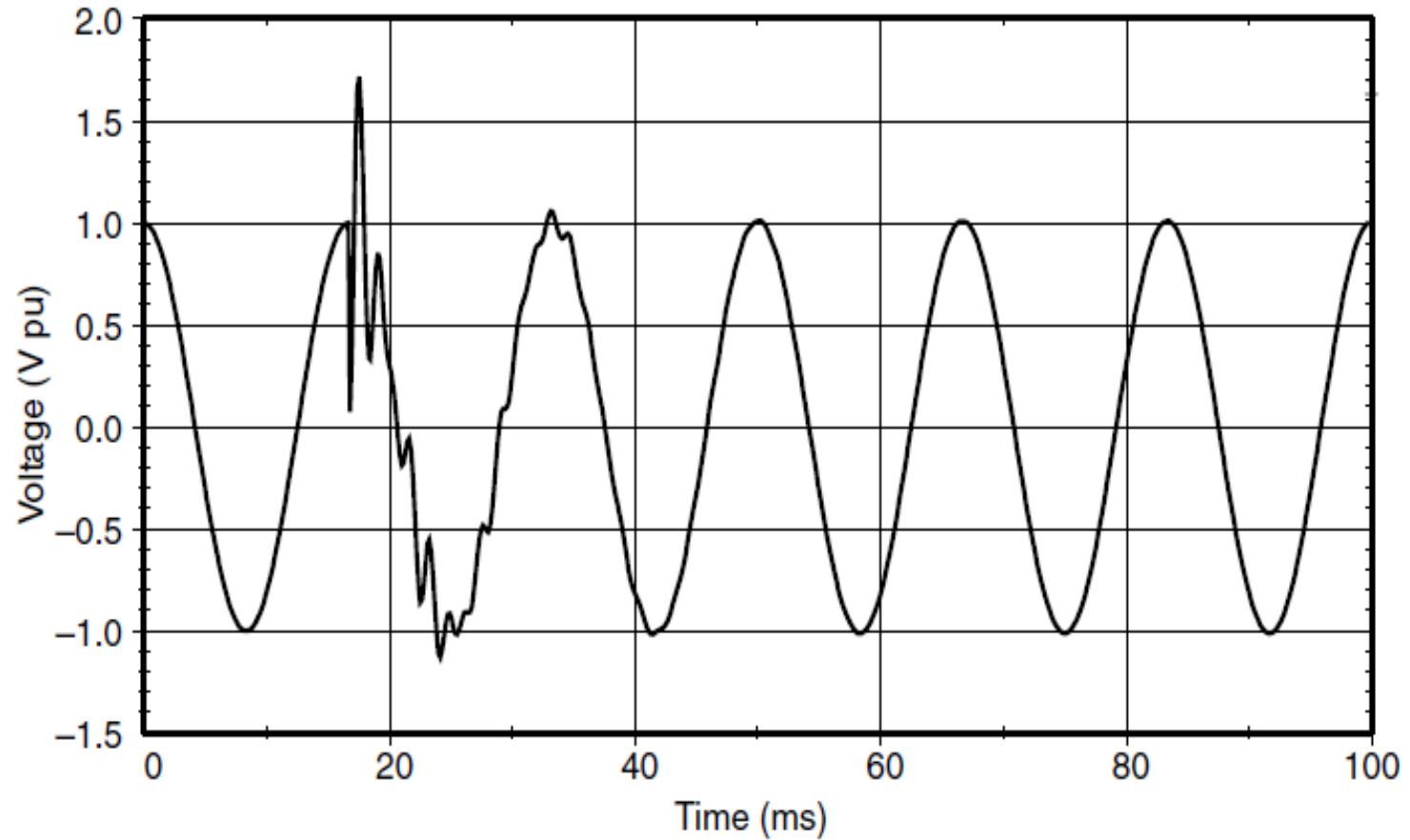
Back-to-back capacitor energization results in oscillatory transient currents in the tens of kilohertz as illustrated in Fig. 2. Cable switching results in oscillatory voltage transients in the same frequency range. Medium-frequency transients can also be the result of a system response to an impulsive transient.

# Long-Duration Voltage Variations

Long-duration variations encompass root-mean-square (rms) deviations at power frequencies for longer than 1 min.

Long-duration variations can be either *overvoltages* or *undervoltages*.

Overvoltages and undervoltages generally are not the result of system faults, but are caused by load variations on the system and system switching operations. Such variations are typically displayed as plots of rms voltage versus time.



**Figure 2.3** Low-frequency oscillatory transient caused by capacitor bank energization. 34.5-kV bus voltage.

## 2.4.1 Overvoltage

An *overvoltage* is an increase in the rms ac voltage greater than 110 percent at the power frequency for a duration longer than 1 min.

Overvoltages are usually the result of load switching (e.g., switching off a large load or energizing a capacitor bank). The overvoltages result because either the system is too weak for the desired voltage regulation or voltage controls are inadequate. Incorrect tap settings on transformers can also result in system overvoltages.

## 2.4.2 Undervoltage

An *undervoltage* is a decrease in the rms ac voltage to less than 90 percent at the power frequency for a duration longer than 1 min.

Undervoltages are the result of switching events that are the opposite of the events that cause overvoltages. A load switching on or a capacitor bank switching off can cause an undervoltage until voltage regulation equipment on the system can bring the voltage back to within tolerances. Overloaded circuits can result in undervoltages also.

## Short-Duration Voltage Variations

- This category encompasses the IEC category of *voltage dips and short interruptions*. Each type of variation can be designated as *instantaneous, momentary, or temporary*, depending on its duration as defined in Table
- Short-duration voltage variations are caused by fault conditions, the energization of large loads which require high starting currents, or intermittent loose connections in power wiring.

Depending on the fault location and the system conditions, the fault can cause either temporary voltage drops (*sags*), *voltage rises (swells)*, or a complete loss of voltage (*interruptions*). *The fault condition can be close to or remote* from the point of interest. In either case, the impact on the voltage during the actual fault condition is of the short-duration variation until protective devices operate to clear the fault.

## **Interruption**

*An interruption occurs when the supply voltage or load current decreases to less than 0.1 pu for a period of time not exceeding 1 min.*

Interruptions can be the result of power system faults, equipment failures, and control malfunctions. The interruptions are measured by their duration since the voltage magnitude is always less than 10 percent of nominal.

### **Sags (dips)**

*A sag is a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations from 0.5 cycle to 1 min.*

The power quality community has used the term *sag* for many years to describe a short-duration voltage decrease.

## Swells

*A swell is defined as an increase to between 1.1 and 1.8 pu in rms voltage*

or current at the power frequency for durations from 0.5 cycle to 1 min.

As with sags, swells are usually associated with system fault conditions,

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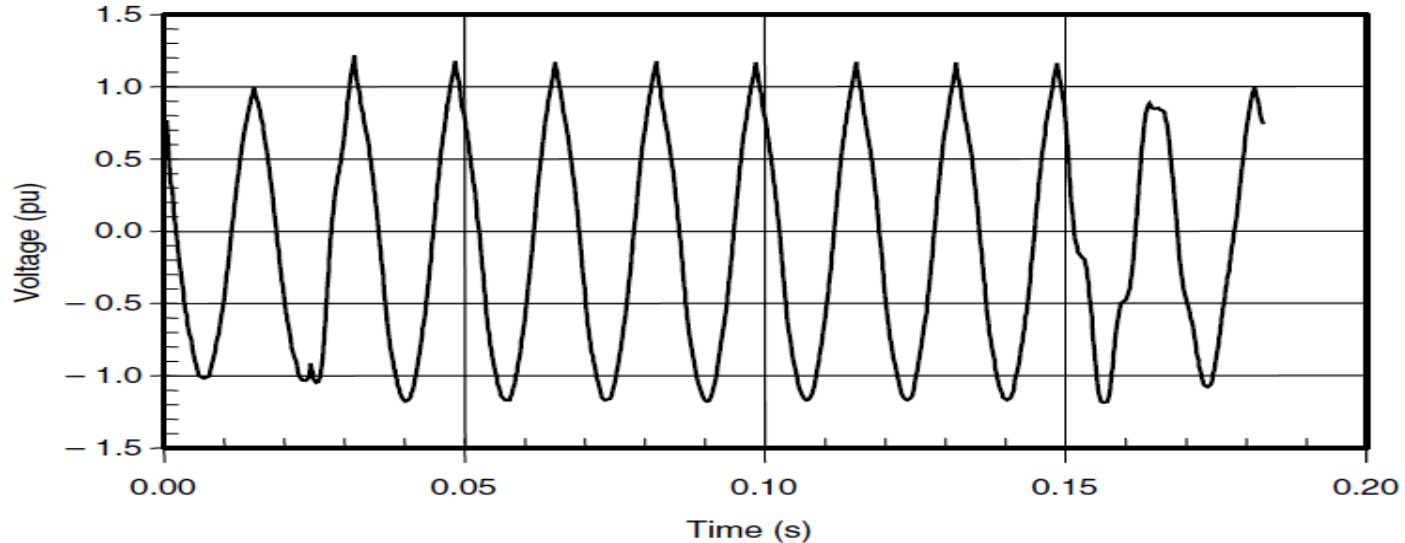


Figure 2.8 Instantaneous voltage swell caused by an SLG fault.

## Voltage Imbalance

*Voltage imbalance (also called voltage unbalance) is sometimes defined as the maximum deviation from the average of the three-phase voltages or currents, divided by the average of the three-phase voltages or currents, expressed in percent*

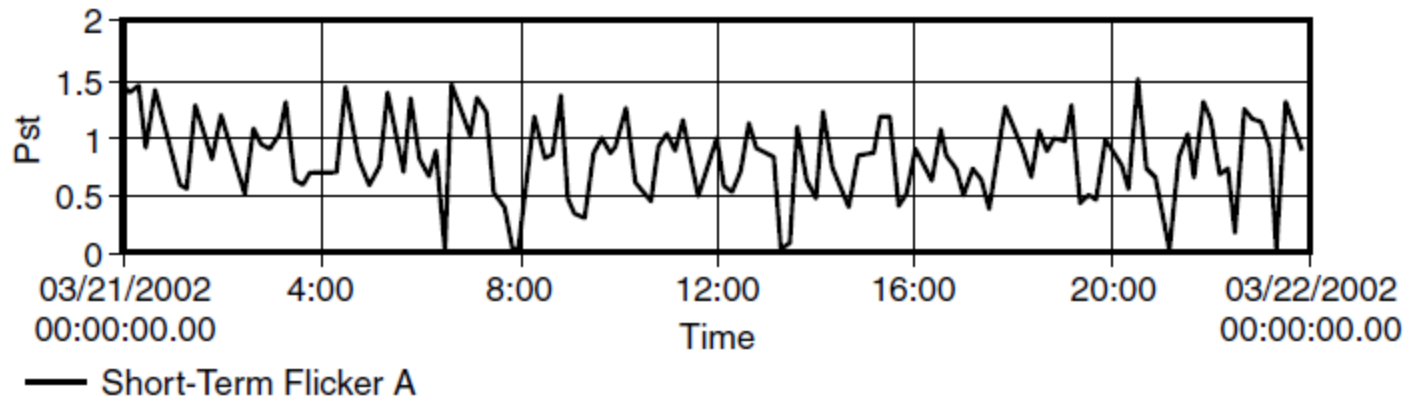
The primary source of voltage unbalances of less than 2 percent is single-phase loads on a three-phase circuit. Voltage unbalance can also be the result of blown fuses in one phase of a three-phase capacitor bank. Severe voltage unbalance (greater than 5 percent) can result from single-phasing conditions.

## **DC offset.**

The presence of a dc voltage or current in an ac power system is termed *dc offset*. This can occur as the result of a *geomagnetic disturbance* or *asymmetry of electronic power converters*. Incandescent light bulb life extenders, for example, may consist of diodes that reduce the rms voltage supplied to the light bulb by half-wave rectification. Direct current in ac networks can have a detrimental effect by biasing transformer cores so they saturate in normal operation. This causes additional heating and loss of transformer life. Direct current may also cause the electrolytic erosion of grounding electrodes and other connectors.

## Flicker

Loads that can exhibit continuous, rapid variations in the load current magnitude can cause voltage variations that are often referred to as flicker. The term *flicker* is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker.



To be technically correct, voltage fluctuation is an electromagnetic phenomenon while flicker is an undesirable result of the voltage fluctuation in some loads.

Categories	Typical spectral content	Typical duration	Typical voltage magnitude
1.0 Transients			
1.1 Impulsive			
1.1.1 Nanosecond	5-ns rise	<50 ns	
1.1.2 Microsecond	1- $\mu$ s rise	50 ns–1 ms	
1.1.3 Millisecond	0.1-ms rise	>1 ms	
1.2 Oscillatory			
1.2.1 Low frequency	<5 kHz	0.3–50 ms	0–4 pu
1.2.2 Medium frequency	5–500 kHz	20 $\mu$ s	0–8 pu
1.2.3 High frequency	0.5–5 MHz	5 $\mu$ s	0–4 pu
2.0 Short-duration variations			
2.1 Instantaneous			
2.1.1 Interruption		0.5–30 cycles	<0.1 pu
2.1.2 Sag (dip)		0.5–30 cycles	0.1–0.9 pu
2.1.3 Swell		0.5–30 cycles	1.1–1.8 pu
2.2 Momentary			
2.2.1 Interruption		30 cycles–3 s	<0.1 pu
2.2.2 Sag (dip)		30 cycles–3 s	0.1–0.9 pu
2.2.3 Swell		30 cycles–3 s	1.1–1.4 pu
2.3 Temporary			
2.3.1 Interruption		3 s–1 min	<0.1 pu
2.3.2 Sag (dip)		3 s–1 min	0.1–0.9 pu
2.3.3 Swell		3 s–1 min	1.1–1.2 pu
3.0 Long-duration variations			
3.1 Interruption, sustained		>1 min	0.0 pu
3.2 Undervoltages		>1 min	0.8–0.9 pu
3.3 Overvoltages		>1 min	1.1–1.2 pu
4.0 Voltage unbalance		Steady state	0.5–2%
5.0 Waveform distortion			
5.1 DC offset		Steady state	0–0.1%
5.2 Harmonics	0–100th harmonic	Steady state	0–20%
5.3 Interharmonics	0–6 kHz	Steady state	0–2%
5.4 Notching		Steady state	
5.5 Noise	Broadband	Steady state	0–1%
6.0 Voltage fluctuations	<25 Hz	Intermittent	0.1–7% 0.2–2 Pst
7.0 Power frequency variations		<10 s	

NOTE: s = second, ns = nanosecond,  $\mu$ s = microsecond, ms = millisecond, kHz = kilohertz, MHz = megahertz, min = minute, pu = per unit.

# Symptoms of poor power quality

## Insulation Failure

Any overvoltage will increase the risk of insulation failure. This holds for system components such as transformers and cables as well as for end-user equipment such as motors. This is obviously a long-term effect and in most cases not significant. Note, however, that a higher voltage during normal operation increases the base from which transient over voltages start. This increases the peak voltage and thus the risk of insulation failure. Again this is probably an insignificant effect.

## **Induction motors:**

Undervoltages will lead to reduced starting torque and increased full-load temperature rise. The reduced starting torque may significantly increase the time needed to accelerate the motor. In some cases the motor may not accelerate at all: It will “stall.”

Overvoltages will lead to increased torque, increased starting current, and decreased power factor. The increased starting torque will increase the accelerating forces on couplings and driven equipment. Increased starting current also causes greater voltage drop in the supply system and increases the voltage dip seen by the loads close to the motor. Although the motor will start quicker, its effect on other load may be more severe.

**Incandescent lamps:** The light output and life of such lamps are critically affected by the voltage. The expected life length of an incandescent lamp is significantly reduced by only a few percent increase in the voltage magnitude.

The lifetime somewhat increases for lower-than-nominal voltages, but this cannot compensate for the decrease in lifetime due to higher-than-nominal voltage. The result is that a large variation in voltage leads to a reduction in lifetime compared to a constant voltage.

**Fluorescent lamps:** The light output varies approximately in direct proportion to the applied voltage. The lifetime of fluorescent lamps is affected less by voltage variation than that of incandescent lamps.

**Resistance heating devices:** The energy input and therefore the heat output of resistance heaters vary approximately as the square of the voltage. Thus a 10% drop in voltage will cause a drop of approximately 20% in heat output.

An undervoltage will lead to an increased duty cycle for any equipment that uses a thermostat (heating, refrigerating, air conditioning). The result is that the total current for a group of such devices will increase. Even though individual heaters behave as a constant-resistance load, a group of them behave as constant-power loads. This phenomenon is one of the contributing factors to voltage collapse.

Electronic equipment may perform less efficient due to an undervoltage. The equipment will also be more sensitive to voltage dips. A higher-than-nominal voltage will make the equipment more sensitive to overvoltages. As the internal voltage control maintains the application voltage at a constant level (typically much lower than the 110 through 230 V mains voltage), a reduction in terminal voltage will lead to an increase in current which gives higher losses and reduced lifetime.

## **Transformers:**

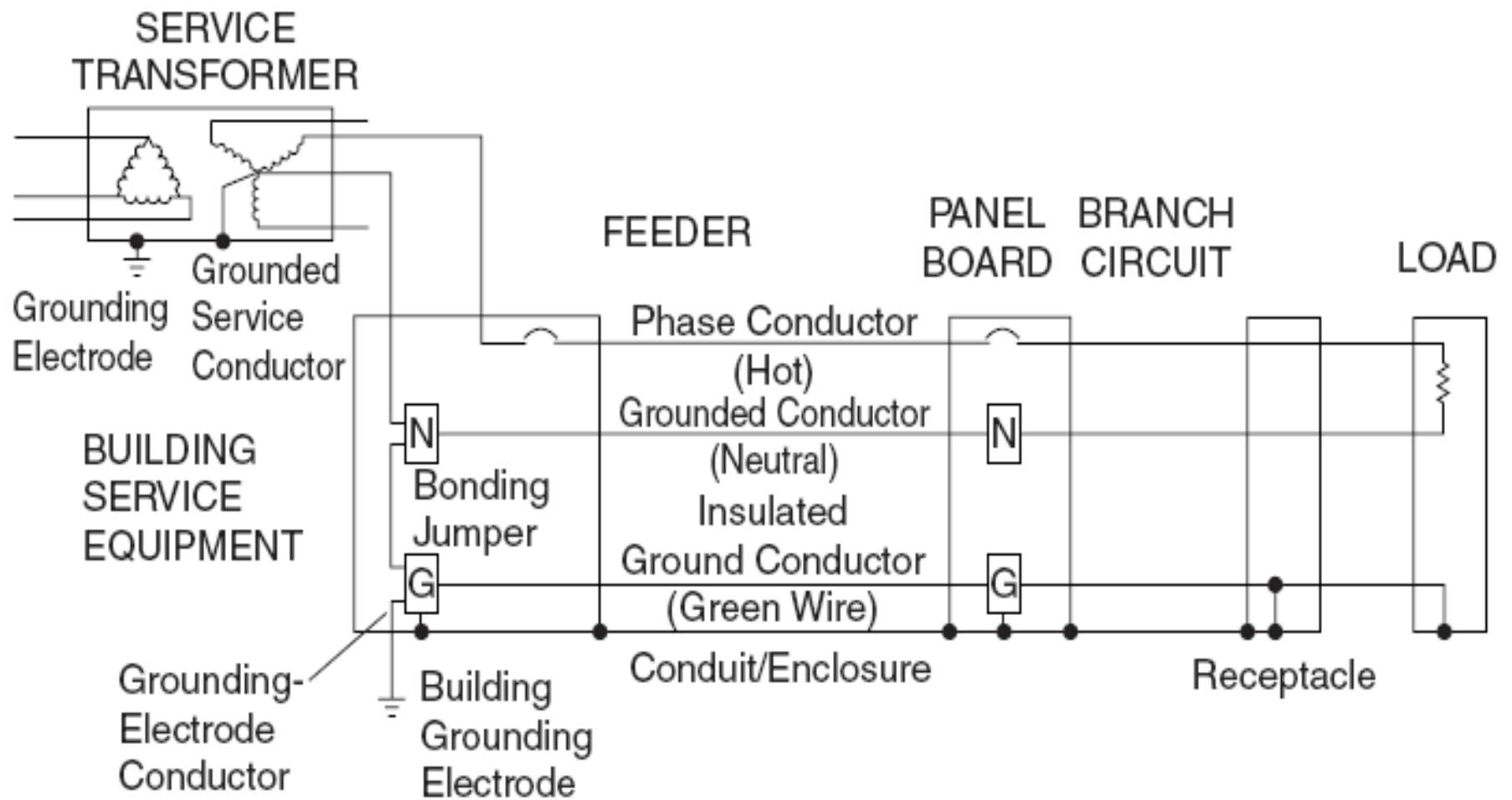
A higher-than-nominal voltage over the transformer terminals will increase the magnetizing current of a transformer. As the magnetizing current is heavily distorted, an increase in voltage magnitude will increase the waveform distortion.

IEEE Dictionary (Standard 100) definition\*

## GROUNDING :

1. A conducting connection, whether intentional or accidental, by which an electric circuit or equipment is connected to the earth, or to some conducting body of relatively large extent that serves in place of the earth.
2. It is used for establishing and maintaining the potential of the earth (or of the conducting body) or approximately that potential, on conductors connected to it; and for conducting ground current to and from the earth (or the conducting body).

- The resistance of the ground-rod connection is important because it influences transient voltage levels during switching events and lightning transients. High-magnitude currents during lightning strokes result in a voltage across the resistance, raising the ground reference for the entire facility. The difference in voltage between the ground reference and true earth ground will appear at grounded equipment within the facility, and this can result in dangerous touch potentials.



**Figure 10.3** Basic elements of a properly grounded electrical system.

# Power Quality Standards

**IEEE Std 1159™-2009**  
(Revision of  
IEEE Std 1159-1995)

## **IEEE Recommended Practice for Monitoring Electric Power Quality**

Sponsor

**Transmission and Distribution Committee  
of the  
IEEE Power & Energy Society**

Approved 18 March 2009

**IEEE-SA Standards Board**

- **Abstract:**
- This recommended practice encompasses the monitoring of electrical characteristics of single-phase and polyphase ac power systems. It includes consistent descriptions of conducted electromagnetic phenomena occurring on power systems. This recommended practice describes nominal conditions and deviations from these nominal conditions that may originate within the source of supply or load equipment or may originate from interactions between the source and the load. Also, this recommended practice discusses power quality monitoring devices, application techniques, and the interpretation of monitoring results.

- Monitoring and measurements can be utilized for power system performance studies as well as compatibility assessment. Brief, generic descriptions of load susceptibility to deviations from nominal power supply conditions are presented to identify which deviations may be of interest. Further, this recommended practice discusses the selection of appropriate measuring instruments, limitations of these instruments, application techniques, and the interpretation of monitoring results.

- An understanding of how power quality events impact the power system and end-use equipment is required in order to make monitoring useful. Proper measuring techniques are required to safely obtain useful, accurate data. Appropriate location of monitors, systematic studies, and interpretation of results will enhance the value of power quality monitoring. The purpose of this recommended practice is to assist users as well as equipment and software manufacturers and vendors by describing techniques for defining, measuring, quantifying, and interpreting electromagnetic disturbances on the power system.

# IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems

IEEE Power and Energy Society

Sponsored by the  
Transmission and Distribution Committee

Abstract: Goals for the design of electrical systems that include both linear and nonlinear loads are established in this recommended practice. The voltage and current waveforms that may exist throughout the system are described, and waveform distortion goals for the system designer are established. The interface between sources and loads is described as the point of common coupling and observance of the design goals will reduce interference between electrical equipment. This recommended practice addresses steady-state limitations. Transient conditions exceeding these limitations may be encountered. This document sets the quality of power that is to be provided at the point of common coupling. This document does not cover the effects of radiofrequency interference; however, guidance is offered for wired telephone systems.

1. The uses of nonlinear loads connected to electric power systems include static power converters, arc discharge devices, saturated magnetic devices, and, to a lesser degree, rotating machines. Static power converters of electric power are the largest nonlinear loads and are used in industry for a variety of purposes, such as electrochemical power supplies, adjustable speed drives, and uninterruptible power supplies. These devices are useful because they can convert ac to dc, dc to dc, dc to ac, and ac to ac.

2. Nonlinear loads change the sinusoidal nature of the ac power current (and consequently the ac voltage drop), thereby resulting in the flow of harmonic currents in the ac power system that can cause interference with communication circuits and other types of equipment.
  
3. These harmonic currents also lead to increased losses and heating in numerous electromagnetic devices (motors, transformers, etc.). When reactive power compensation, in the form of power factor improvement capacitors, is used, resonant conditions can occur that may result in high levels of harmonic voltage and current distortion when the resonant condition occurs at a harmonic associated with nonlinear loads.

# Recommended harmonic limits

- Because managing harmonics in a power system is considered a joint responsibility involving both end users and system owners or operators, harmonic limits are recommended for both voltages and currents.
- The recommended values in this clause are based on the fact that some level of voltage distortion is generally acceptable and both system owners or operators and users must work cooperatively to keep actual voltage distortion below objectionable levels.

**Table 1—Voltage distortion limits**

<b>Bus voltage <math>V</math> at PCC</b>	<b>Individual harmonic (%)</b>	<b>Total harmonic distortion THD (%)</b>
$V \leq 1.0 \text{ kV}$	5.0	8.0
$1 \text{ kV} < V \leq 69 \text{ kV}$	3.0	5.0
$69 \text{ kV} < V \leq 161 \text{ kV}$	1.5	2.5
$161 \text{ kV} < V$	1.0	1.5 <sup>a</sup>

<sup>a</sup>High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal whose effects will have attenuated at points in the network where future users may be connected.

**Table 2—Current distortion limits for systems rated 120 V through 69 kV**

Maximum harmonic current distortion in percent of $I_L$						
Individual harmonic order (odd harmonics) <sup>a, b</sup>						
$I_{sc}/I_L$	$3 \leq h < 11$	$11 \leq h < 17$	$17 \leq h < 23$	$23 \leq h < 35$	$35 \leq h \leq 50$	TDD
$< 20^c$	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
$> 1000$	15.0	7.0	6.0	2.5	1.4	20.0

<sup>a</sup>Even harmonics are limited to 25% of the odd harmonic limits above.

<sup>b</sup>Current distortions that result in a dc offset, e.g., half-wave converters, are not allowed.

<sup>c</sup>All power generation equipment is limited to these values of current distortion, regardless of actual  $I_{sc}/I_L$ .

where

$I_{sc}$  = maximum short-circuit current at PCC

$I_L$  = maximum demand load current (fundamental frequency component)  
at the PCC under normal load operating conditions

# Reasons for Grounding

- **1. *Personnel safety:***
  - Personnel safety is the primary reason that all equipment must have a safety equipment ground.
  - This is designed to prevent the possibility of high touch voltages when there is a fault in a piece of equipment.
  - There should be no “floating” panels or enclosures in the vicinity of electric circuits. In the event of insulation failure or inadvertent application of moisture, any electric charge which appears on a panel, enclosure, or raceway must be drained to “ground” or to an object which is reliably grounded.

## 2. *Grounding to assure protective device operation*

A ground fault return path to the point where the power source neutral conductor is grounded is an essential safety feature. The *NEC and some local wiring* codes permit electrically continuous conduit and wiring device enclosures to serve as this ground return path.

## *3.Noise control.*

The primary objective of grounding for noise control is to create an equipotential ground system. Potential differences between different ground locations can stress insulation, create circulating ground currents in low-voltage cables, and interfere with sensitive equipment that may be grounded in multiple locations.

# Thank You