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EE6005 – POWER QUALITY

Unit – I – Introduction to Power Quality

By

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Unit - I

INTRODUCTION TO POWER QUALITY :

Terms and definitions: Overloading - under voltage - over voltage. Concepts of transients – short duration variations such as interruption - long duration variation such as sustained interruption. Sags and swells - voltage sag - voltage swell - voltage imbalance - voltage fluctuation - power frequency variations. International standards of power quality. Computer Business Equipment Manufacturers Associations (CBEMA) curve.

Power Quality

- There can be completely different definitions for power quality, depending on one's frame of reference.
- A utility may define power quality as reliability and show statistics demonstrating that its system is 99.98% reliable.
- A manufacturer of load equipment may define power quality as those characteristics of the power supply that enable the equipment to work properly.

Power Quality

- Power quality is generally used to express the **quality of the voltage**.
- Voltage quality is concerned with **deviation of the voltage from ideal**. The ideal voltage is a single frequency sine wave of constant amplitude and frequency.
- Current quality is concerned with the **deviation of current from ideal.** The ideal current is a single frequency sine wave of constant amplitude and frequency with the additional requirement that current sinewave is inphase with voltage sine wave

Power Quality - Definition

- Any power problem manifested in **voltage, current or frequency deviations** that results in failure or **misoperation of customer equipment.**

- IEEE (Institution of Electrical and Electronics Engineering) 519-1995 defines the term power quality “refers to a **wide variety of electromagnetic phenomena** that characterizes **voltage and current at a given time** and at a **given location on the power system**”.

Power Quality - Definition

- IEC(International Electrotechnical Commission) 61000-4-30 defines power quality as " the characteristics of the electricity at a given point on an electrical system evaluated against a set of reference technical parameters".
- A simple and perhaps more concise definition might state: " power quality is a set of equipment to function in its intended manner without significant loss of performance or life expectancy.

Power Quality - Definition

- Power quality can be defined as "the measure, analysis and improvement of bus voltage usually a **load bus voltage to maintain that voltage to be a sinusoidal at rated voltage and frequency"**

Power Quality - Definition

- Power quality is an abnormal behavior on a power system arising in the form of voltage and/or current, which adversely affects the normal operation of electrical or electronic equipment.
- It is defined in another way, power quality is **any deviation of the voltage or current waveform from its normal sinusoidal wave shape.**

Power Quality

- These disturbances include, but are not limited to sag, under voltage, interruption, swell, over voltage, transient, harmonics, voltage flicker and any other distortion to the sinusoidal waveform. Occurrence of one or more of such disturbances is called a power quality event.

Power Quality

- The power supply system can control only the voltage quality. It has no control over the current that particular load might draw. There is always a close relationship between voltage and current in any practical power system. Although the generators may provide a near perfect sine-wave voltage, the current passing through the impedance of the system can cause a variety of disturbances to the voltage.

Power Quality

- The current resulting from a short circuit causes the voltage to sag or disappear completely, as the case may be.
- Currents from lightning strokes passing through the power system cause high impulse voltages that frequently flash over insulation and lead to other phenomena.
- Distorted currents from harmonics-producing loads also distort the voltage as they pass through the system impedance. Thus a distorted voltage is presented to other and users.

Power Quality

The increased interest in power quality can be summarized as:

- Poor power quality can affect the accuracy of utility metering.
- Poor power quality can cause protective relays to malfunctioning
- Poor power quality can result in equipment downtime and/or damage, resulting in a loss of production.
- Poor power quality can result in increased costs due to the preceding effects.
- Poor power quality can result in problems with electromagnetic compatibility and noise.

Quality of Supply

This term covers technical aspects as well as non-technical aspects like the interaction between the customer and the network operator, e.g. the speed with which the network operator reacts to complaints etc. what level of customer service does the network operator offer? How quick will a fault in the network be repaired? Questions like those are part of quality of supply.

Quality of Supply

The following definitions should apply according to the council of European Regulators working Group on Quality of Supply.

- Customer service
- Continuity of supply (usually referred to as reliability)
- Voltage quality (usually referred to as power quality)
- Current quality

Quality of Supply

Some examples of customer service indicators utilized include:

- Customer satisfaction
- Customer complaints
- Customer meter and billing accuracy
- Response to customer enquiries
- Customer call/wait times
- Time required for new service connections
- Estimating charges for work
- Emergency/storm response
- Safety/health

Quality of Supply

Categories of voltage quality include:

- Power frequency variation
- Flicker
- Magnitude of the supply voltage
- Harmonics and inter-harmonics
- Voltage imbalance
- Voltage sags
- Momentary interruptions
- Transients

Quality of Supply

Current quality is concerned with the deviation of the current from a normal sinusoidal waveform and is determined by the load utilized by the customer. Thus the customer can affect the level of current quality.

Normally , the network operator has no legal rights to prevent a customer to connect any load to the network. If a certain load harmfully affects the power quality, the network operator can at least advise the customer to install mitigation equipment like a filter etc. to increase the quality of power.

Major Power Quality Issues

- Power frequency disturbances
- Power system Transients
- Electromagnetic interferences
- Power system Harmonics
- Electrostatic discharges
- Grounding and bonding
- Power factor

Characterization of power quality disturbances

- Short duration variations
- Long duration variations
- Transients
- Waveform distortion

Characteristics of power quality events

- Sag
- Swell
- Interruption

} **Short duration variations**

- Overvoltage
- Under voltage
- Sustained interruption

} **Long duration variations**

Characteristics of power quality events

Transients

- Impulse
- Oscillatory

Waveform distortion

- DC offset
- Harmonics
- Interharmonics
- Notching
- Noise

Voltage imbalance

Voltage fluctuation

Power frequency variations

Over Voltage

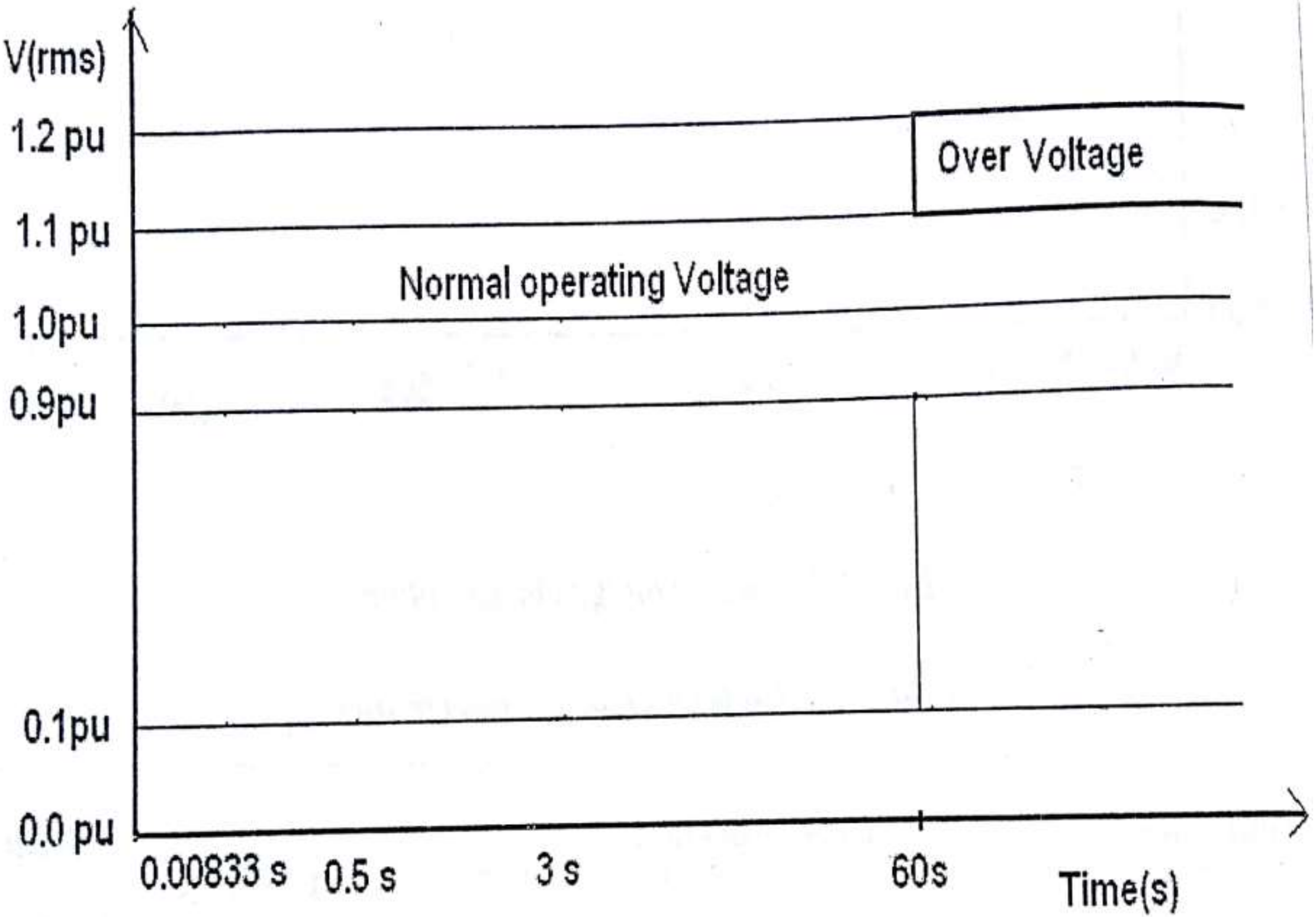
- An over voltage is an **increase in the RMS ac voltage greater than 110 percent** at the power frequency for a duration **longer than 1 min**.

Causes :

- **Load switching** (e.g. switching off a large load or energizing a capacitor bank).
- **Incorrect tap settings on** transformers.
- The overvoltage result because either the **system is too weak for the desired voltage regulation** or voltage controls are inadequate.

Effects:

- Circuit breaker will be opened.
- Fuse will be blown.


V(rms)
1.2 pu
1.1 pu
1.0pu
0.9pu
0.1pu
0.0 pu
Over Voltage
Normal operating Voltage
0.00833 s
0.5 s
3 s
60s
Time(s)

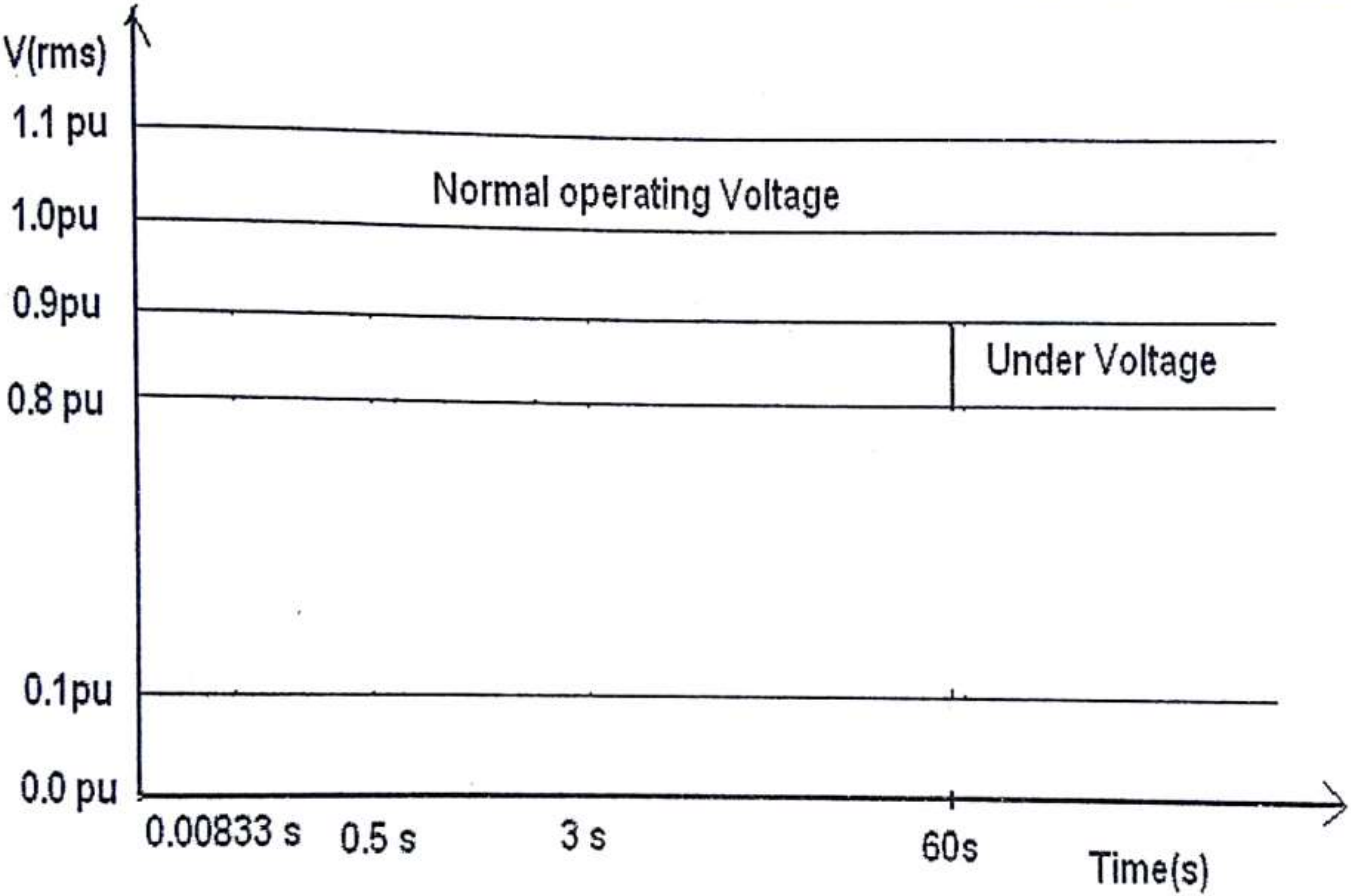
Under Voltage

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

Causes:

- Under voltages are result of **switching events that are the opposite of the events** that cause overvoltages.
- A **load switching ON** or a **capacitor bank switching off (deenergization)** can cause an under voltage until voltage back to within tolerances.

Effects : Overloaded circuits can result in under voltages also.


V(rms)
1.1 pu
Normal operating Voltage
1.0pu
0.9pu
Under Voltage
0.8 pu
0.1pu
0.0 pu
0.00833 s
0.5 s
3 s
60s
Time(s)

Sustained Interruption

When a **supply voltage has been zero for a period of time in excess of 1 min**, then the long duration variation is called sustained interruption.

Causes

- Protective devices – fuses and breakers
- System maintenance

Effects

- Leads to permanent in nature and require manual intervention and restoration

Transients

- The term transients denotes **undesirable and momentary in nature.**
- It is defined as pertaining to or designating a phenomenon or a quantity that **varies between two consecutive steady states** during a time interval that is short compared to the time scale of interest.
- Transients is **unidirectional impulse of either polarity** or damped oscillatory wave with first peak occurring in either polarity.

Transients - Classification

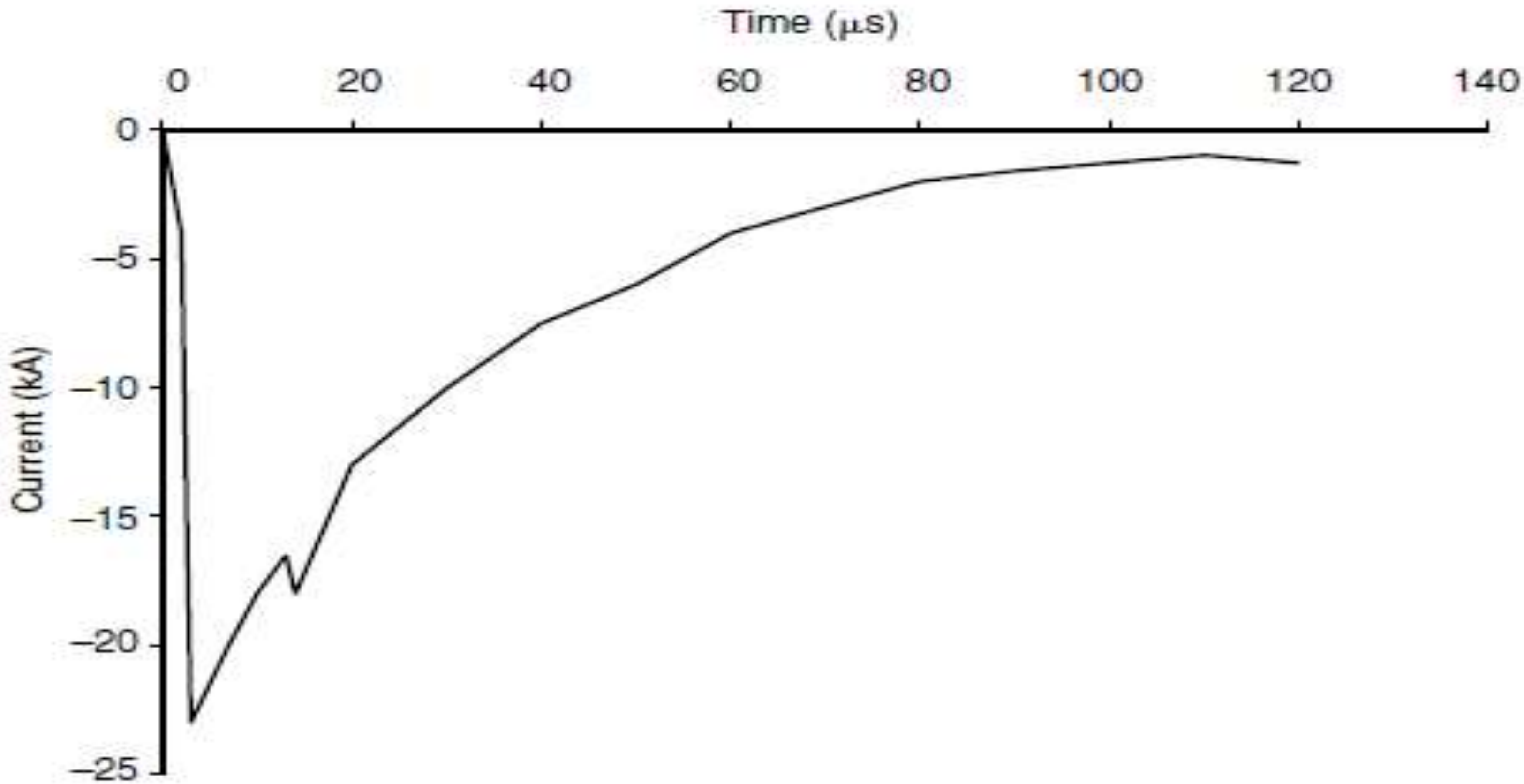
- Transients can be classified into two categories, impulsive and oscillatory.

Impulsive Transients: - It 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).

- Impulsive transients are normally characterized by their rise and decay time, which can also be revealed by their spectral content.
- **Example :** A 1.2/50µs 2000-volt (V) impulsive transient nominally rises from zero to its peak value of 2000 V in 1.2µs and then decays to half of its peak value in 50µs.

Transients - Classification

- **Causes** : lightning.
- **Effects:** Excite power system resonance circuits and produce oscillatory transients.



Lightning stroke current impulsive transient.

Transients - Classification

- Because of high frequencies involved, the shape of impulsive transients can be changed quickly by circuit components and may have significantly different characteristics when viewed from different parts of the power system.
- Impulsive transients can excite the natural frequency of power system circuits and produce oscillatory transients.

Types of impulse transients

1. **Nanosecond Impulse transient**: Rise time of 5 nano second and duration less than 50 nano seconds.
2. **Microsecond Impulse transient**: Rise time of 1 micro second and duration that lasts between 50 nano seconds.
3. **Millisecond Impulse transient:** Rise time of 0.1 milli second and duration greater than 1 milli second.

Transients - Classification

Oscillatory transient: It 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**.

- An oscillatory transient consists of a voltage or current whose instantaneous value changes polarity rapidly.
- It is described by its spectral content (predominant frequency), duration and magnitude. The spectral content subclasses into **high, medium and low frequency**.

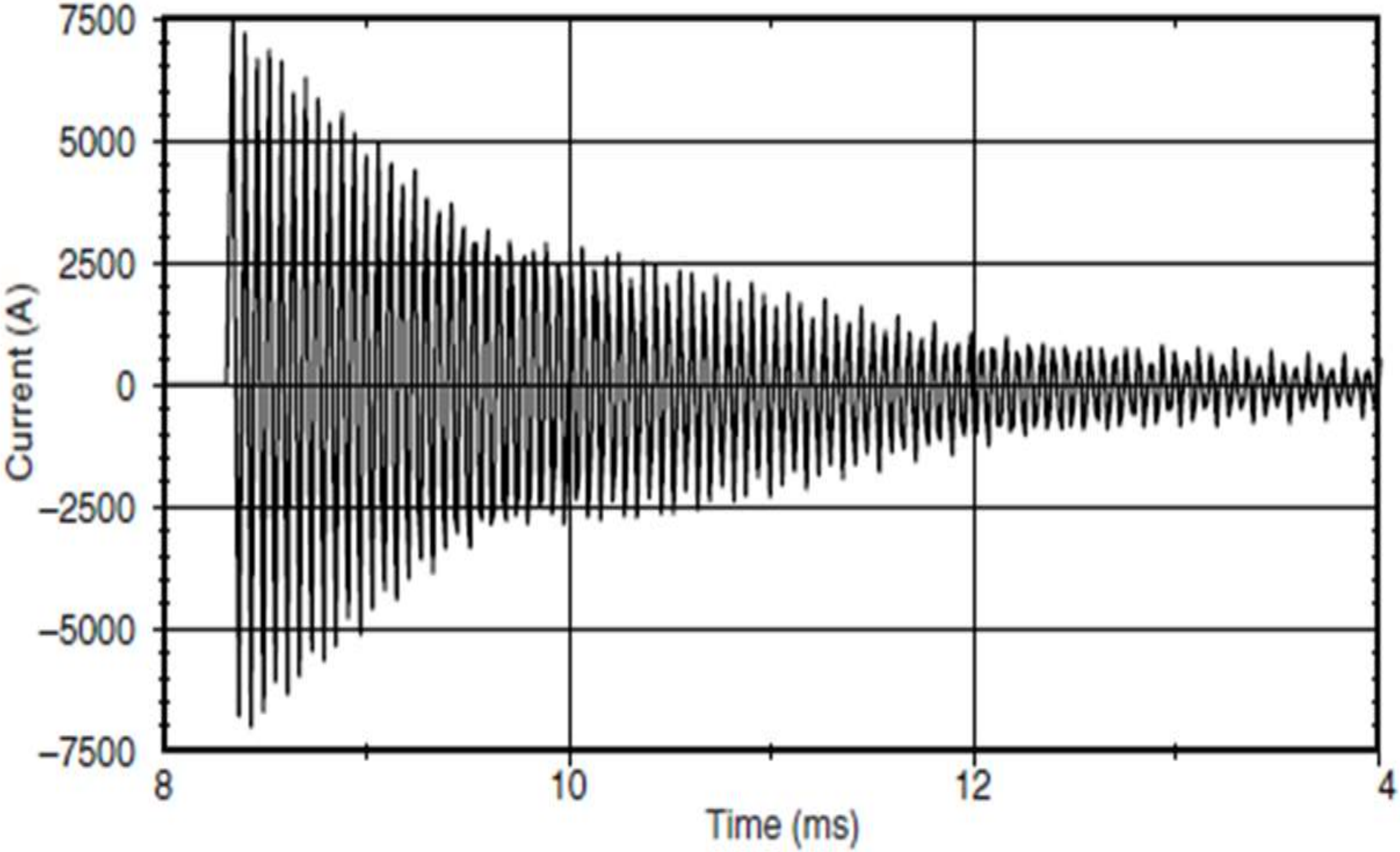
Transients - Classification

Causes:

- **Back-to-back capacitor energization** results in oscillatory transient currents in the tens of kilohertz.
- **Cable switching** results in oscillatory voltage transients.

Effects :

- **Ferroresonance**
- **Resonating low frequency components** in transformer inrush current.



Oscillatory transient current caused by back-to-back capacitor switching.

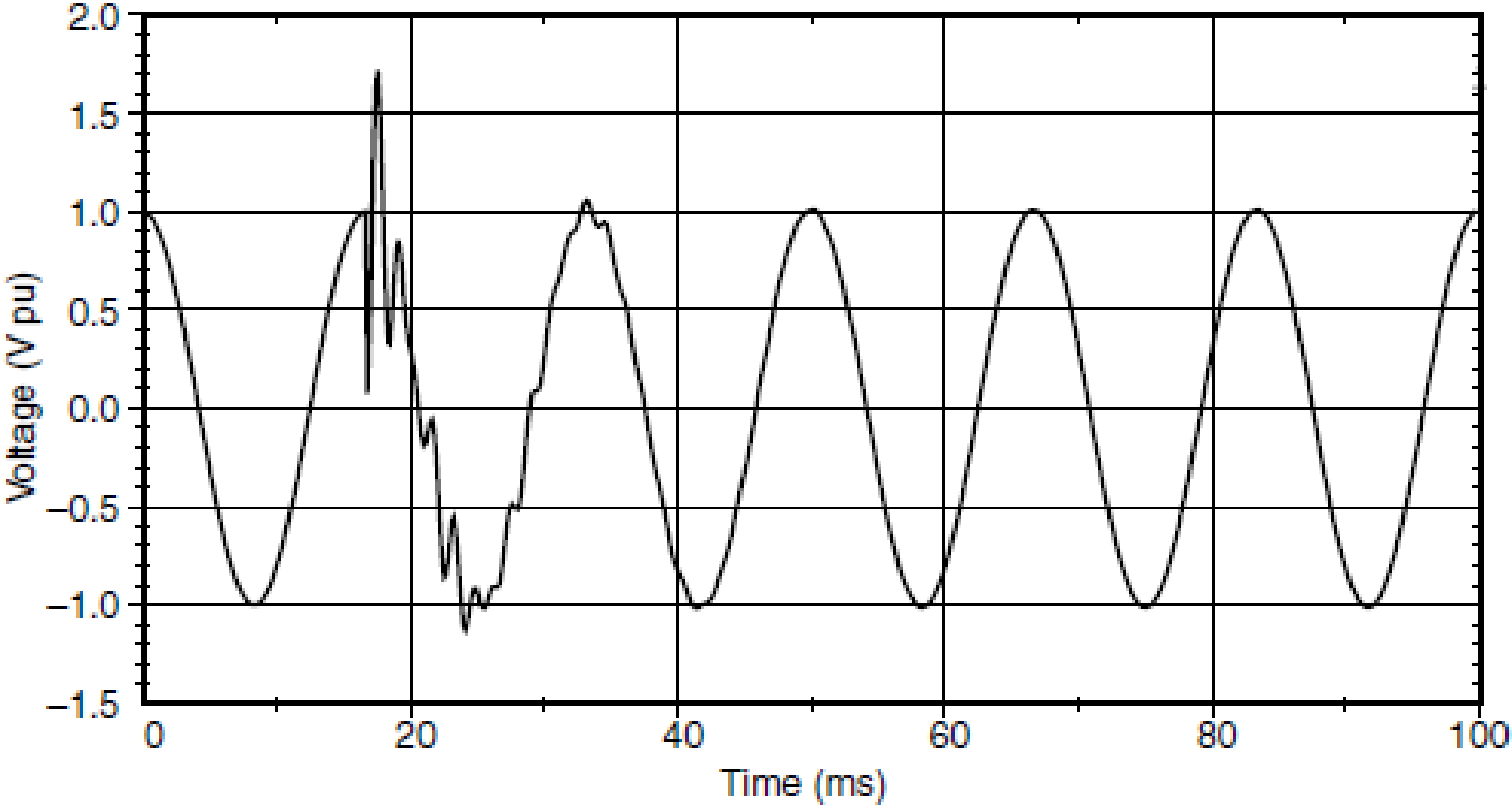
Transients - Classification

- **High frequency transients :** Oscillatory transients with primary **frequency component greater than 500kHz** and a typical duration measured in microseconds (or several cycles of the principal frequency) are considered as high-frequency transients. These transients are often the result of a local system response to an impulsive transient.
- **Medium frequency transients :** A transient with primary **frequency component between 5 and 500kHz** with duration measured in the tens of microseconds (or several cycles of the principal frequency) is termed a medium frequency transients.

Transients - Classification

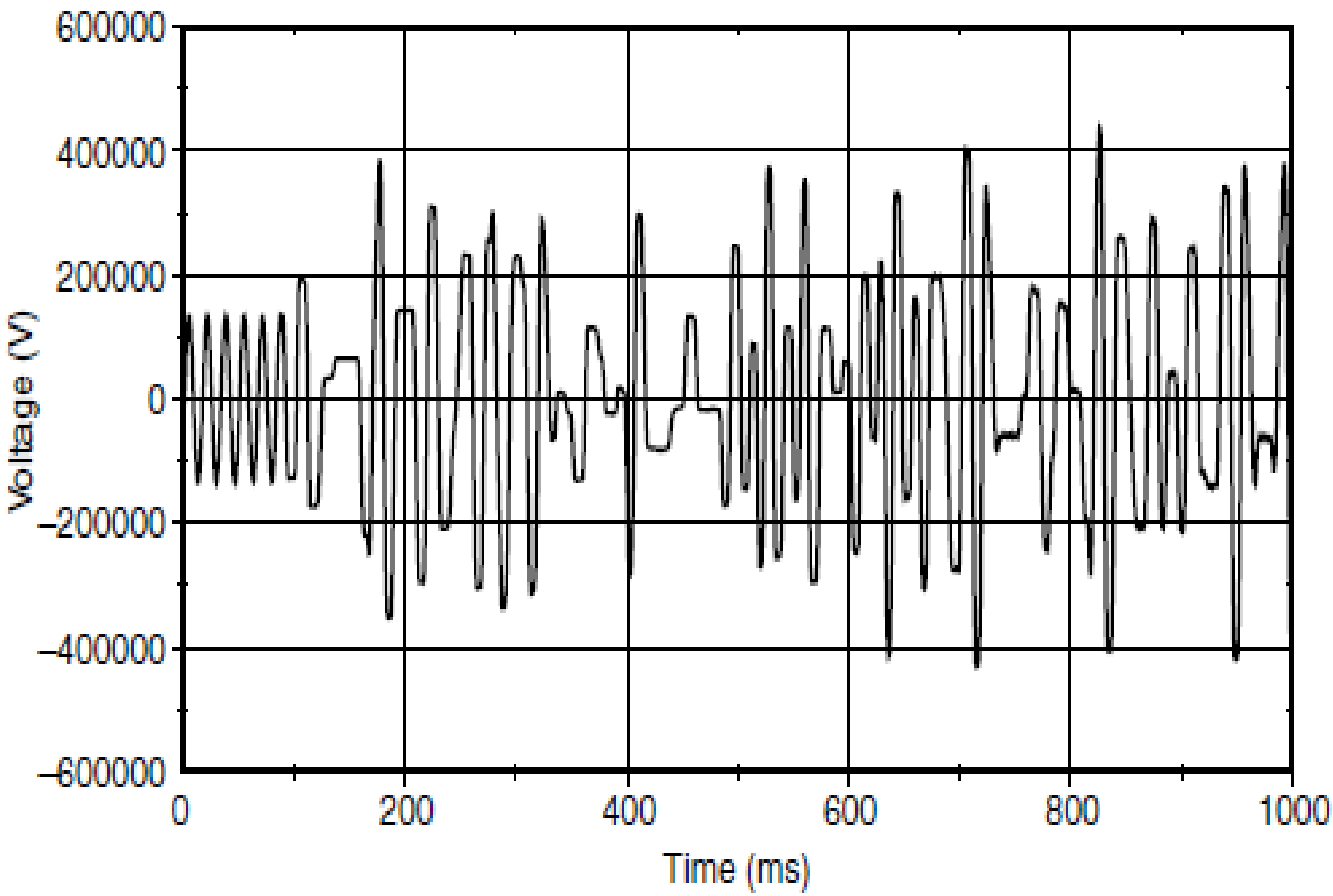
- **Low frequency transients :** A transient with a primary frequency component **less than 5 kHz** and a duration from 0.3 to 50 ms, is considered a low frequency transients.
- This category of phenomena is frequently encountered on utility sub-transmission and distribution systems. The most frequent is capacitor bank energization, which typically results in an oscillatory voltage transient with a primary frequency between 300 and 900Hz.

Transients - Classification



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

Transients - Classification



Low-frequency oscillatory transient caused by ferroresonance of an unloaded transformer.

Short-Duration voltage Variations

Short-Duration voltage variations are **rms deviations at power frequency not grater than 1 minute**.

Types

- Sags
- Swells
- Interruptions

Interruptions

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**.

- There are three types of interruptions based on the time period that the interruptions occur.

1. Momentary interruption
2. Temporary interruption
3. Sustained interruption

Causes

- Protective devices – fuses and breakers
- System maintenance

Effects

- Leads to permanent in nature and require manual intervention and restoration

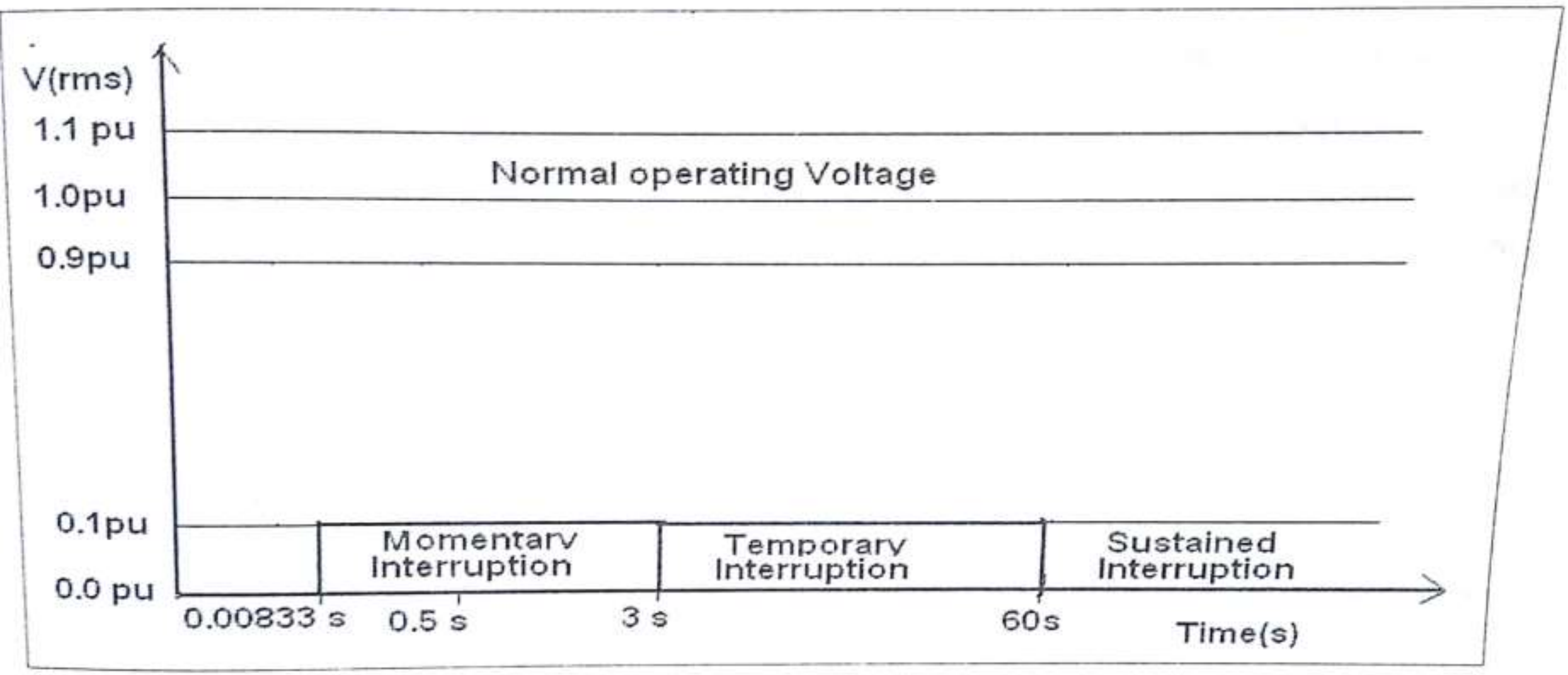


Fig. 1.6. Interruption Classification

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 duration from **0.5 cycle to 1 min**.

Causes:

- fuse or breaker operation
- motor starting
- capacitor switching
- due to re-closer operation

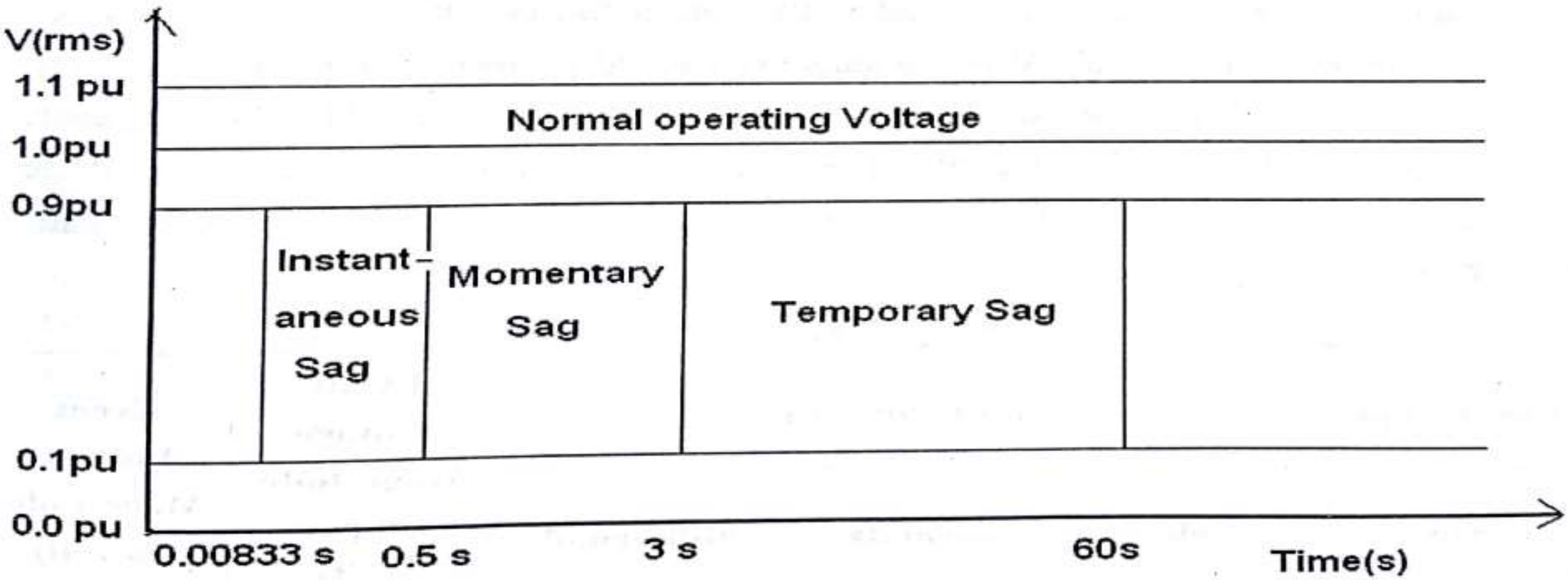
Effects:

- Cause interruption to sensitive equipment such as adjustable-speed drives, relays and robots.

Sags (Dips)

- Based on the time duration and voltage magnitude, sag is further classified as:

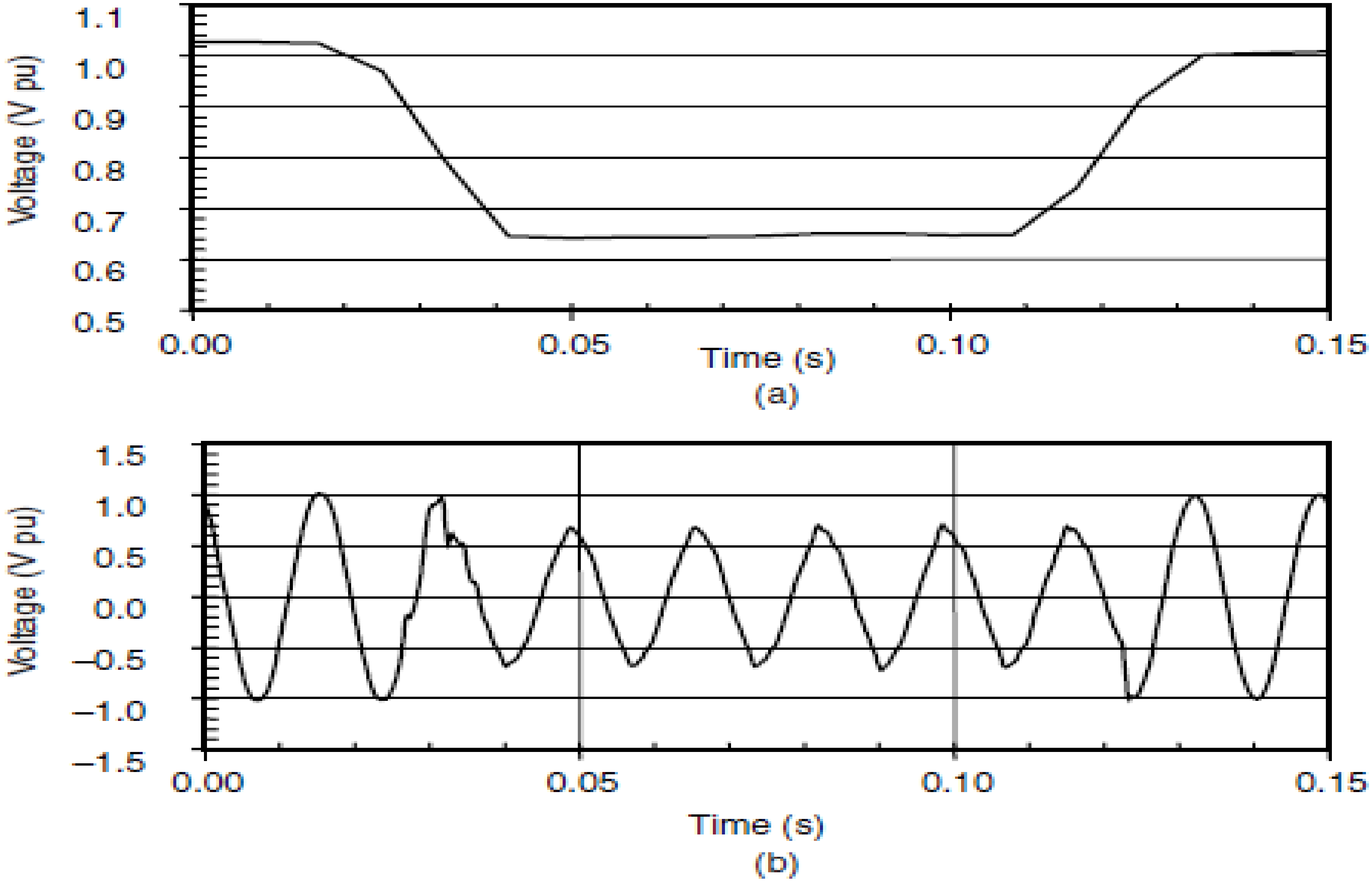
1. Instantaneous sag
2. Momentary sag
3. Temporary sag



Sags (Dips)

- **Instantaneous sag** is said to occur when the RMS voltage decreases between **0.1 and 0.9 per unit** for time duration of **0.00833 second to 0.5 second**.
- **Momentary sag** is said to occur when the RMS voltage decreases between **0.1 and 0.9 per unit** for time duration of **0.5 second to 3 seconds.**
- **Temporary sag** is said to occur when the RMS voltage decreases between **0.1 and 0.9 per unit** for time duration of **3 to 60 seconds.**

Sags (Dips)



Voltage sag caused by an SLG fault. (*a*) RMS waveform for voltage sag event. (*b*) Voltage sag waveform.

Swells

- A swell is defined as an **increase to between 1.1 and 1.8 p.u.** in **RMS voltage or current** at the **power frequency** for durations from **0.5 cycle to 1 min**.

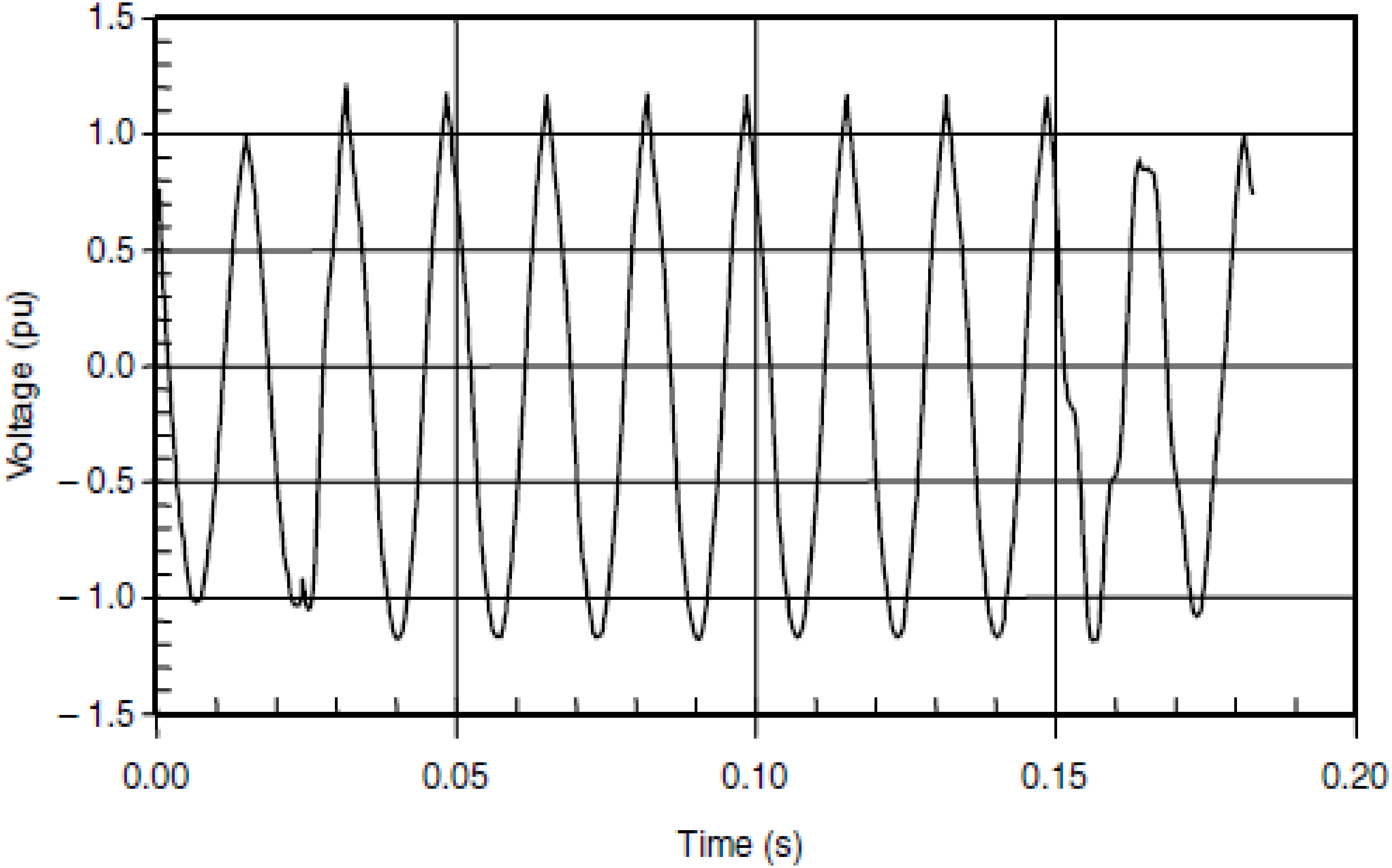
Causes:

- During single line to ground fault.
- Caused by switching off a large load or energizing a large capacitor bank.
- System impedance and grounding
- Faulted four wire system

Effects:

- Brownout or outage

Swells



Instantaneous voltage swell caused by an SLG fault.

Swells Classification

- **Instantaneous swell** is said to occur when the RMS voltage increases between **1.1 and 1.8 per unit** for time duration of **0.008333 second to 0.5second**.
- **Momentary swell** is said to occur when the RMS voltage increases between **1.1 and 1.4 per unit** for time duration of **0.5 seconds to 3 seconds.**
- **Temporary swell** is said to occur when the RMS voltage increases between **1.1 and 1.2 per unit** for time duration of **3 to 60 seconds**.

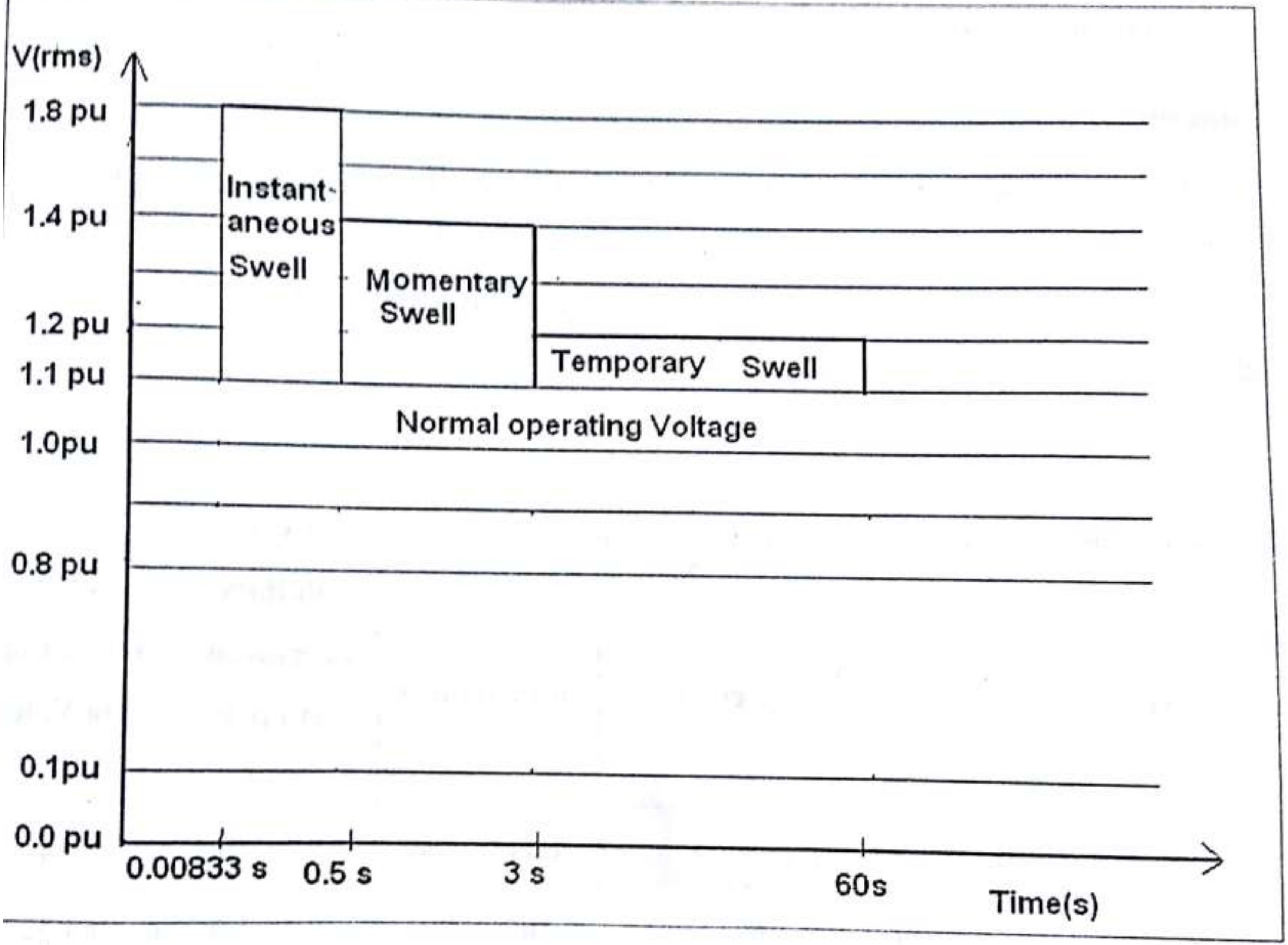


Fig. 1.5. Swell Classification

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**.

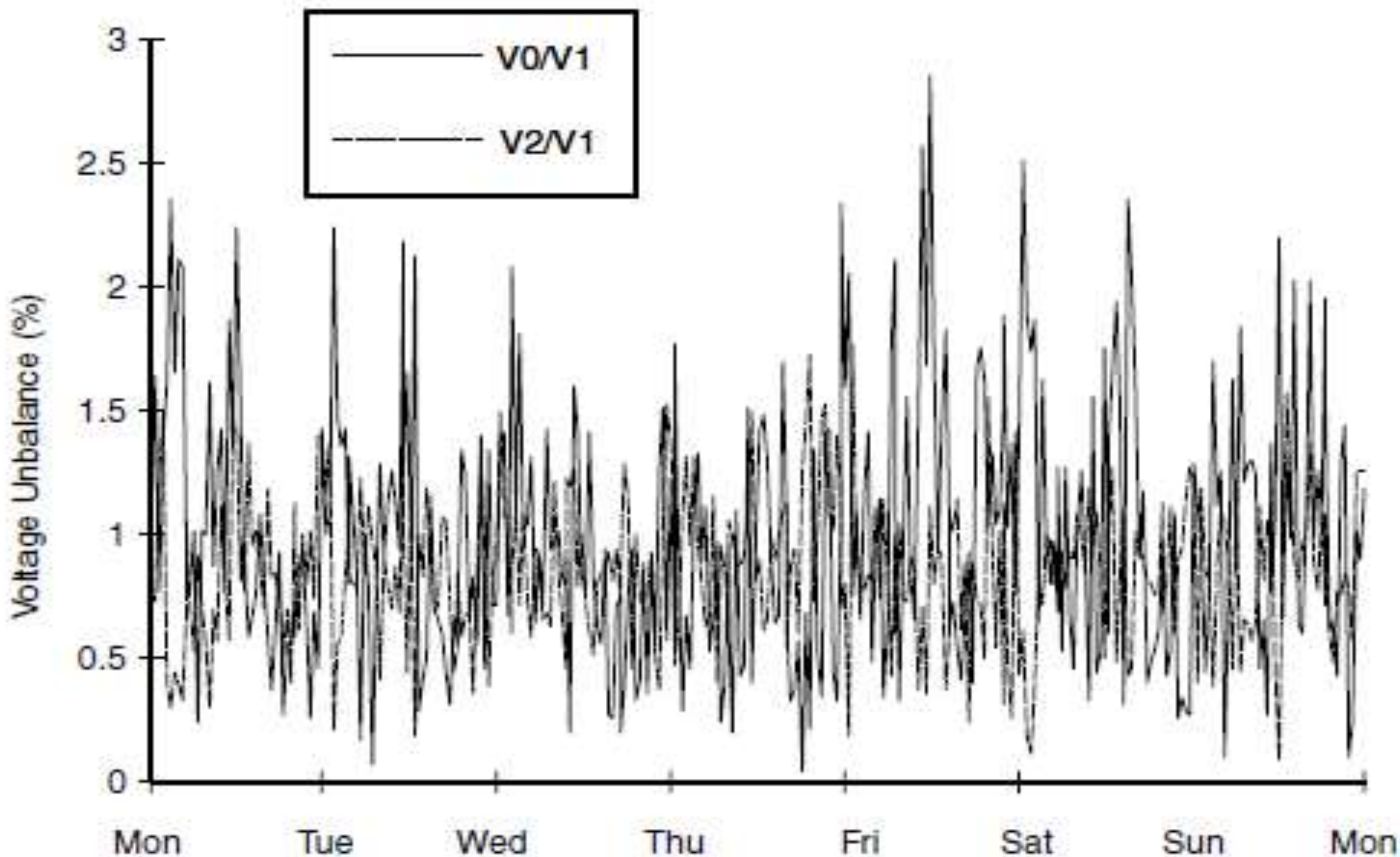
- $\boldsymbol{Voltage\ imbalance} = \dfrac{\boldsymbol{maximum\ deviation\ from\ average\ voltage}}{\boldsymbol{average\ voltage}} \times 100$

- $where, \boldsymbol{average\ voltage} = \dfrac{\boldsymbol{sum\ of\ voltage\ of\ each\ phase}}{\boldsymbol{3}}$

Voltage Imbalance

- Imbalance is more rigorously defined in the standard using symmetrical components. The ratio of either the negative or zero sequence components to the positive sequence component can be used to specify the percent unbalance.
- The most recent standard specify that the negative sequence method to be used.

Voltage Imbalance



Voltage unbalance trend for a residential feeder.

Voltage Imbalance

Causes:

- The primary source of voltage unbalances is single-phase loads on a three-phase circuit.
- 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.

Effects:

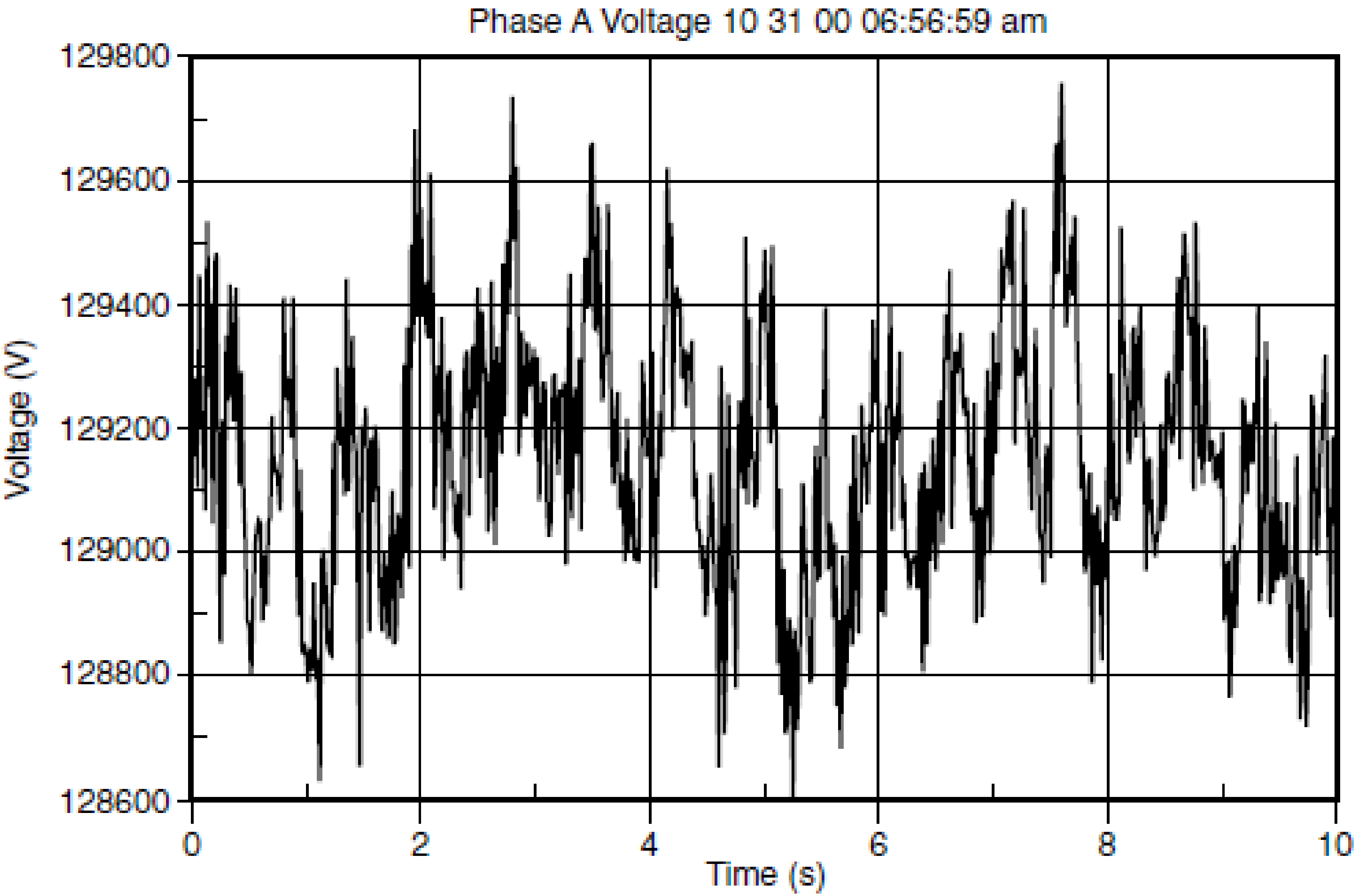
- It cause reverse-rotating air gap field in induction machine, increasing heat loss and temperature rise.

Voltage Fluctuations

Voltage fluctuations are **systematic variations of the voltage envelope** or a **series of random voltage changes**, the magnitude of which **does not normally exceed the voltage ranges of 0.9 to 1.1 pu.**

- **Causes:** Devices like **electric arc furnaces and welders** that have continuous, rapid changes in load current cause voltage fluctuations.
- **Effects:** Voltage fluctuations can cause **incandescent and fluorescent lights to blink rapidly**.
- This **blinking of lights is often referred to as "flicker"**.

Voltage Fluctuations



Example of voltage fluctuations caused by arc furnace operation.

Voltage Fluctuations

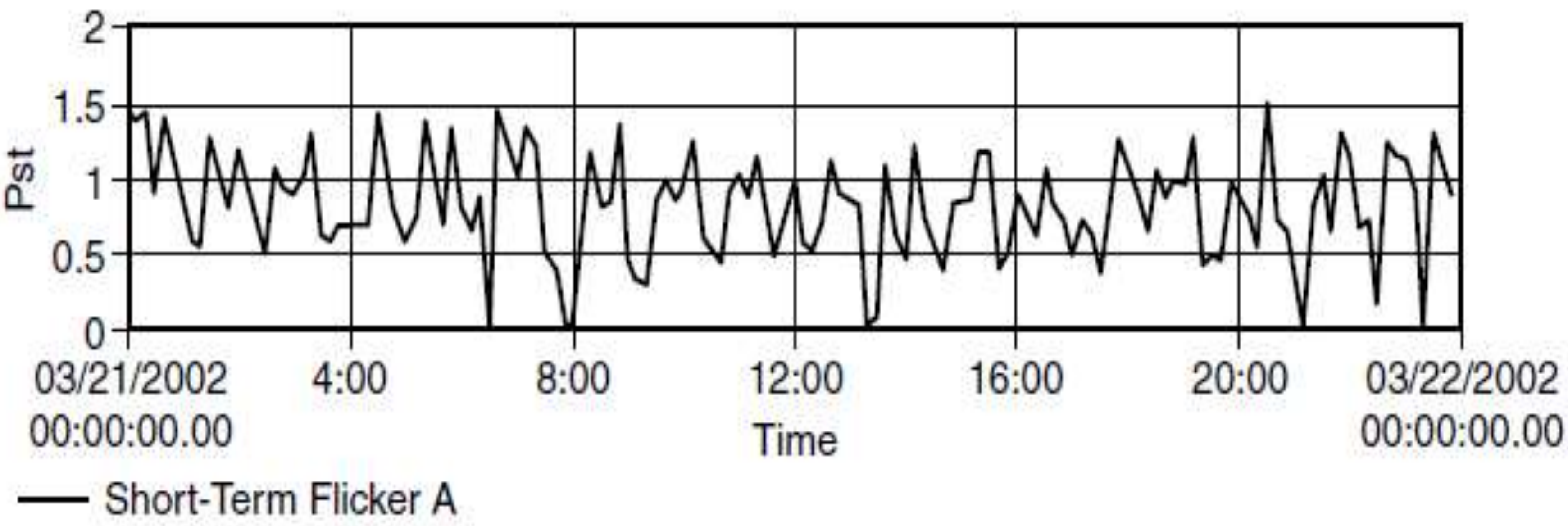
- This change in **light intensity occurs at frequencies of 6 to 8 Hz** and is visible to the human eye.
- **Loads that can exhibit continuous, rapid variations in the load current magnitude** can cause voltage variations that are often referred to as **flicker**.
- The term flicker is derived from the impact of the voltage fluctuation on lamps such that they are perceived by the human eye to flicker.
- The flicker signal is defined by its RMS magnitude expressed as a percent of fundamentals.

Voltage Fluctuations

- The measurement method simulates the lamp/eye/brain transfer function and produces a fundamental metric called short-term flicker sensation (P_{st}).
- This value is normalized to 1.0 to represent the level of voltage fluctuations sufficient to cause noticeable flicker to 50% of a sample observing group.
- Another measure called long-term flicker sensation (P_{lt}).

Voltage Fluctuations

- Figure illustrates a trend of P_{st} measurement taken at a 161 KV substation bus sewing an arc furnace load.



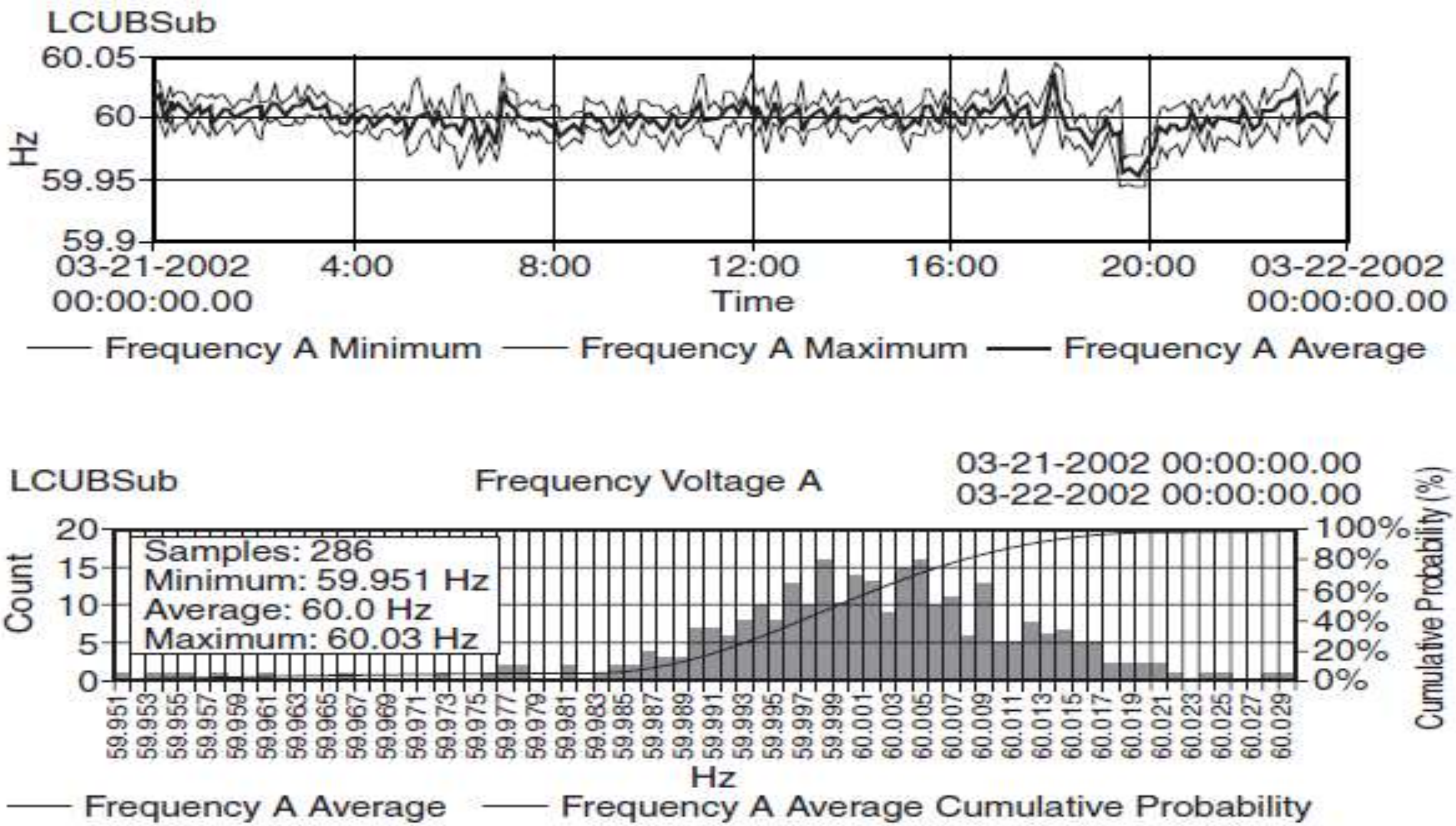
Flicker (Pst) at 161-kV substation bus measured according to IEC Standard 61000-4-15. (*Courtesy of Dranetz-BMI / Electrotek Concepts.*)

Power Frequency Variations

- Power frequency variations are defined as the **deviation of the power system fundamental frequency from it specified nominal value** (e.g.50 or 60 Hz).
- The power system frequency is directly related to the rotational speed of the generators supplying the system.
- The specified frequency **variation should be** within the **limits of ±2.5%** Hz at all time for grid network

Power Frequency Variations

- Figure shows frequency variations for a 24-hour period on a typical 13 kV substation bus.



Power frequency trend and statistical distribution at 13-kV substation bus. (*Courtesy of Dranetz-BMI / Electrotek Concepts.*)

Power Frequency Variations

Causes:

- faults on the **bulk power transmission system**,
- a **large block of load being disconnected** or a **large source of generation going-off**.

Effects:

For sensitive electronic equipment , the result will be

1. Data corruption
2. Hard drive crash
3. Keyboard lockup
4. Program failure
5. Component damage

Waveform Distortion

- Wave form distortion is defined as a **steady-state deviation from an ideal sine wave of power frequency** principally characterized by the **spectral content of the deviation**.

- There are five primary types of waveform distortion

1. **DC offset**
2. **Harmonics**
3. **Interharmonics**
4. **Notching**
5. **Noise**

DC offset

- The **presence of a dc voltage or current in an ac power system is termed dc offset.**

Causes:

- Geomagnetic disturbance
- Effect of half wave rectification
- Use of life extenders in incandescent lighting

Effects:

- Electrolytic erosion of grounding electrodes and other connectors.
- Saturation, heating and loss of transformer life.

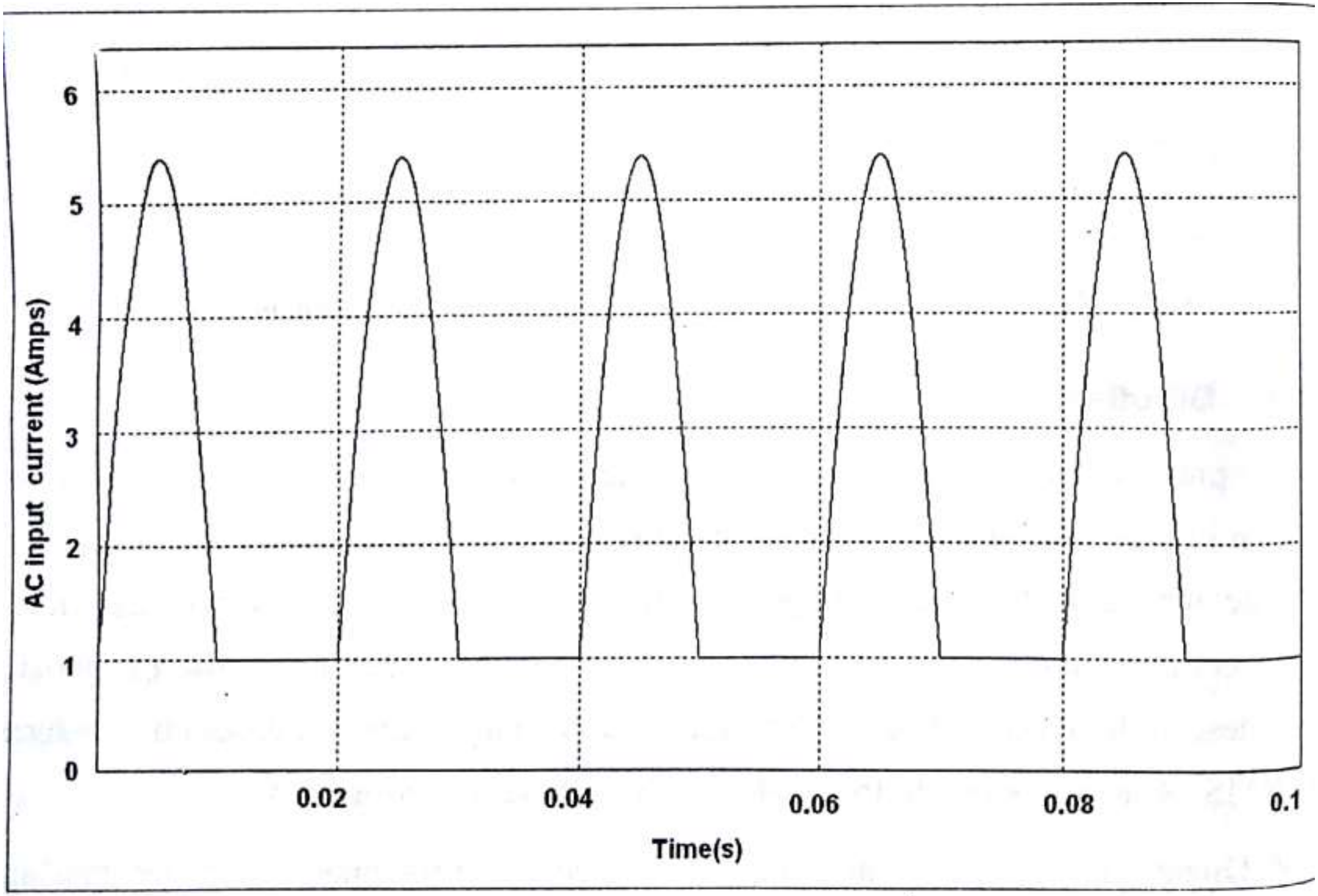


Fig. 1.17. (b) Input current waveform consists of DC offset due to half wave rectification

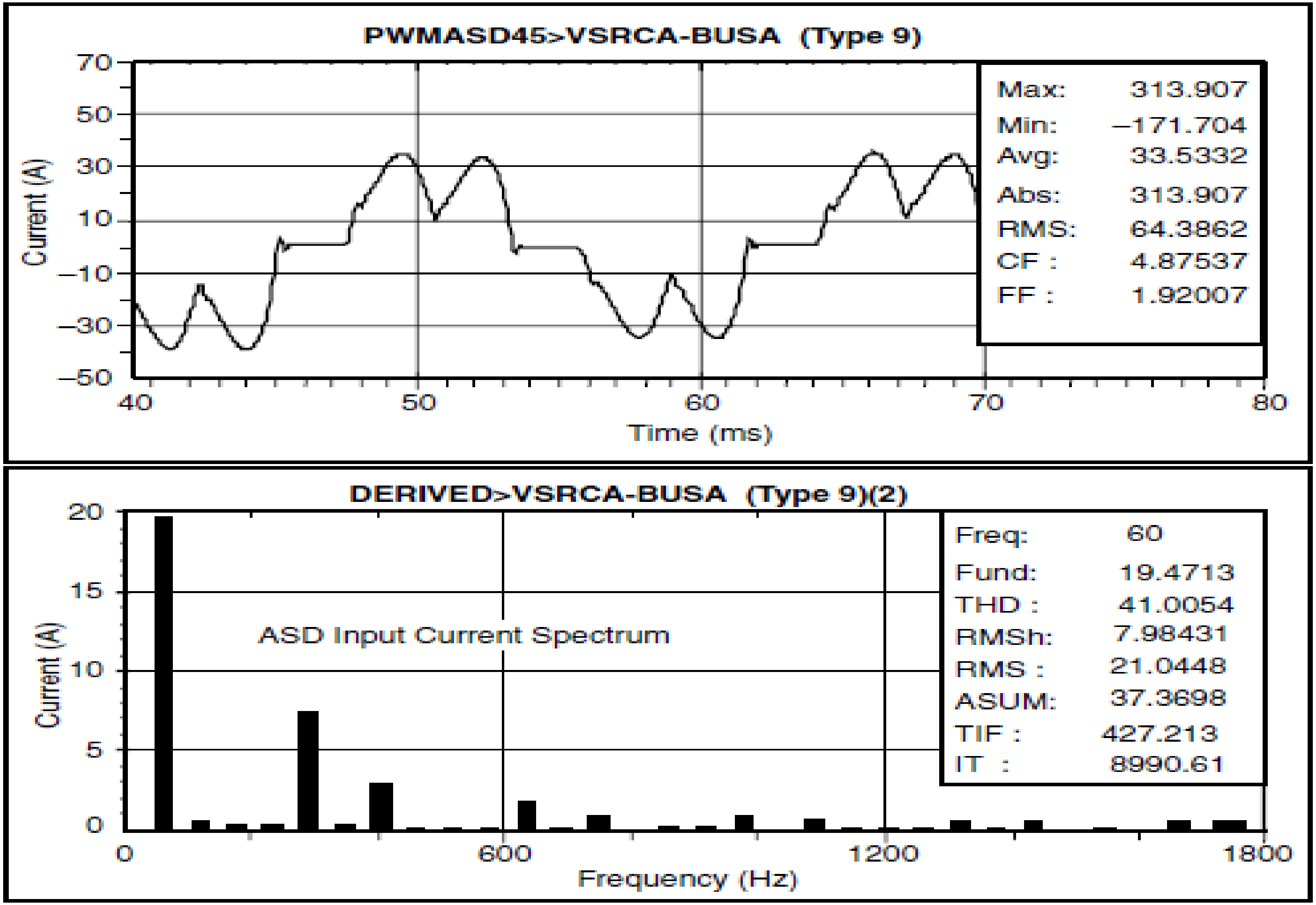
Harmonics

- *Harmonics* are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate (termed the *fundamental* frequency ; usually 50 or 60 Hz).
- The *total harmonic distortion* (THD), as a measure of the effective value of harmonic distortion.

Harmonics

- IEEE Standard 519-1992 defines another term, the *total demand distortion* (TDD). This term is the same as the total harmonic distortion except that the distortion is expressed as a percent of some rated load current rather than as a percent of the fundamental current magnitude at the instant of measurement.
- Causes: nonlinear characteristics of devices and loads on the power system.
- Effects : Voltage harmonics causes communication errors and hardware damage due to unexpected overheating of components, voltage fluctuation, flicker in computer monitor

Harmonics



Current waveform and harmonic spectrum for an ASD input current.

Interharmonics

- Voltages or currents having frequency components that are not integer multiples of the frequency at which the supply system is designed to operate (e.g., 50 or 60 Hz) are called *interharmonics.* They can appear as discrete frequencies or as a wideband spectrum.
- SOURCES:

Static frequency converters

Cycloconverters

Induction furnaces and arcing devices

Power line carrier signals

Interharmonics

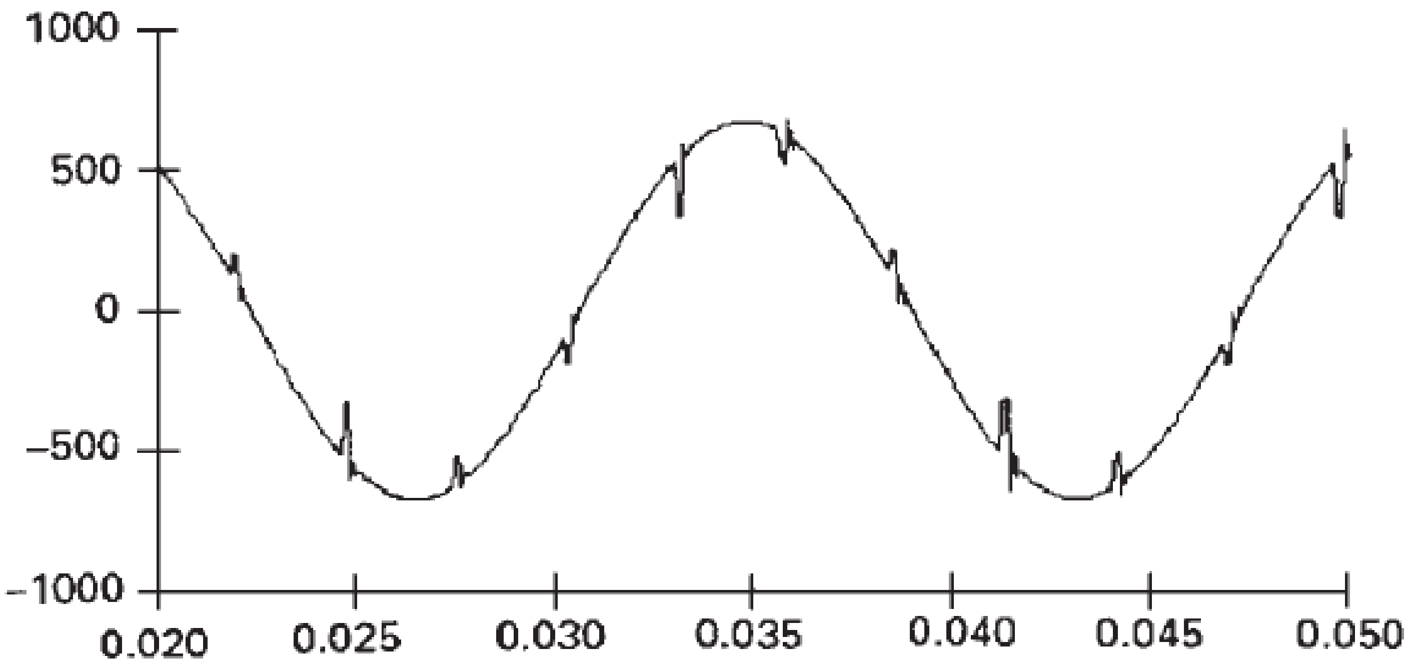
- EFFECTS:

It affects power line carrier signaling system.

It induces visual flicker in display devices such as CRT

Notching

- *Notching* is a periodic voltage disturbance caused by the normal operation of power electronic devices when current is commutated from one phase to another.



Example of voltage notching caused by a three-phase converter.

Notching

Cause:

Current commutation in power electronic devices

Effect:

During this period, there is a momentary short circuit between two phases, pulling the voltage as close to zero as permitted by system impedances.

Noise

- *Noise* is defined as 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.
- Causes: power electronic devices,

  control circuits, arcing equipment,

  loads with solid-state rectifiers, and switching power supplies.
- Effects: It disturbs electronic devices such as programmable controllers and micro computers.

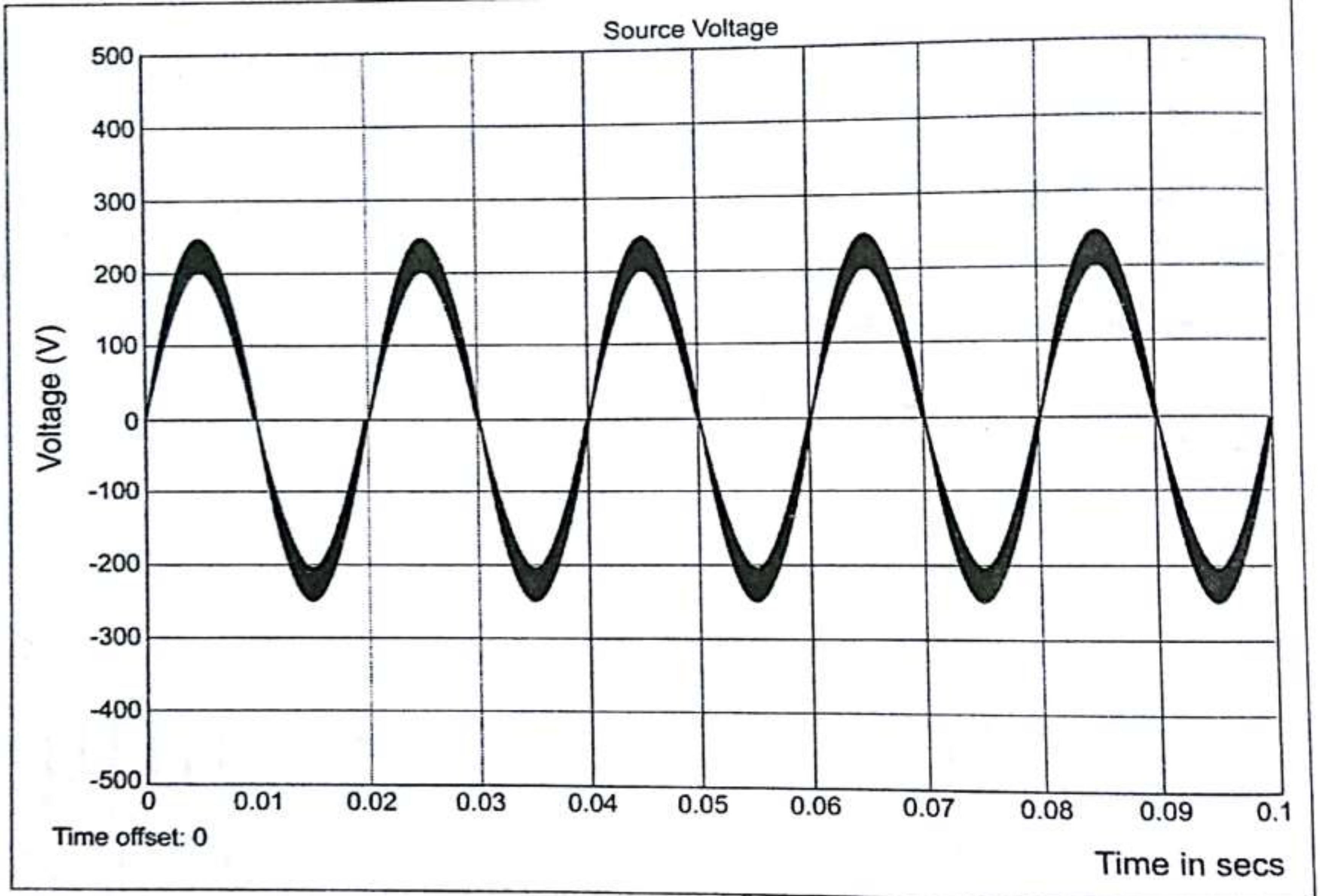


Fig. 1.21. Voltage waveform contaminated with random white noise

Power Quality Evaluation Procedure

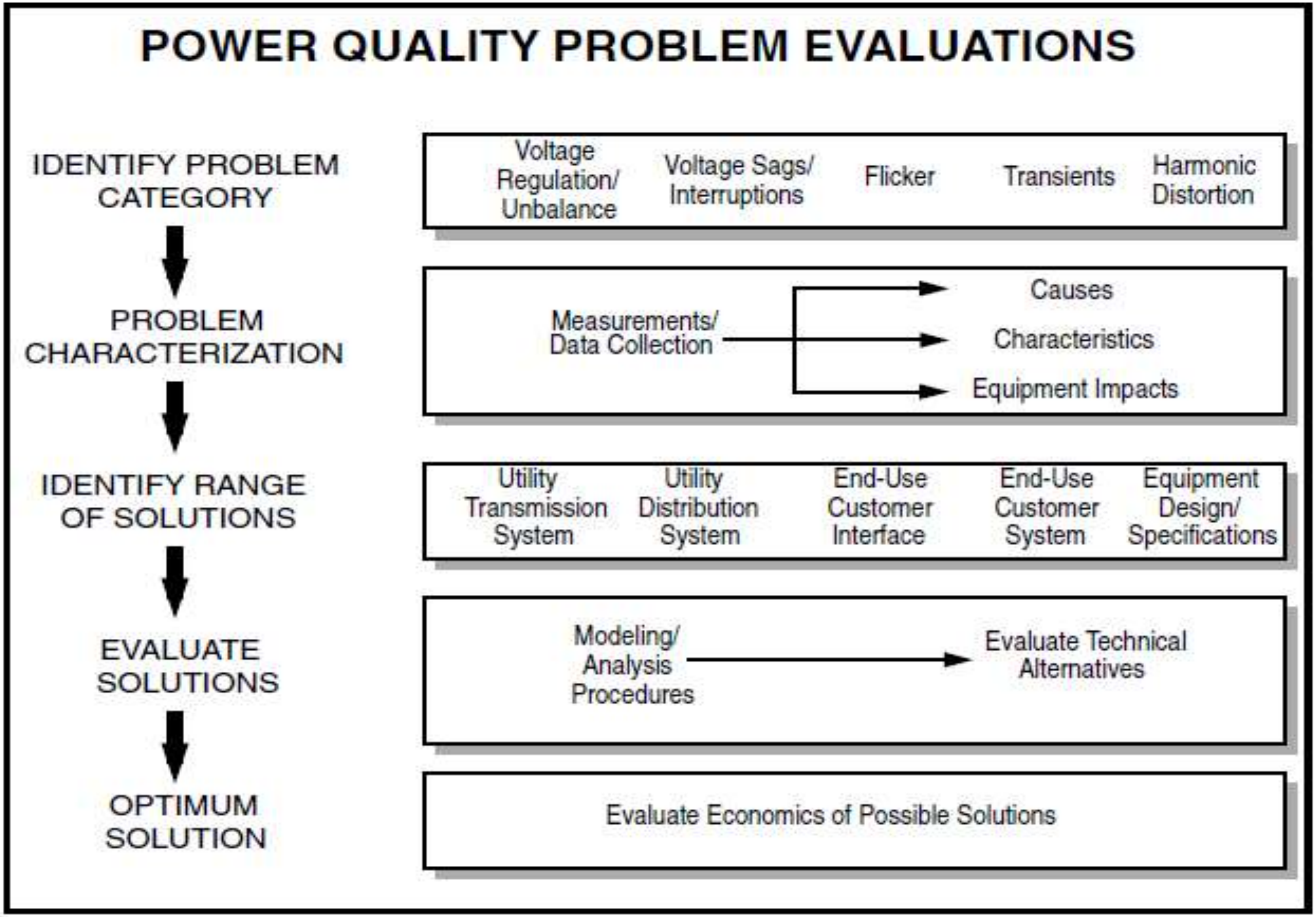
- Evaluation: it involves an existing power quality problem or from a new design or from proposed changes to the system
- Measurement: it will play an important role for almost any power quality concern. This is the primary method of characterizing the problem or the existing system that is being evaluated. When performing the measurement, it is important to record impacts of the power quality variations at the same time so that problems can be correlated with possible causes.

Power Quality Evaluation Procedure

- Solutions: Solutions need to be evaluated using a system viewpoint, and both the economics and the technical limitations must be considered. Possible solutions are identified at all levels of the system from utility supply to the end-user equipment being affected. Solutions that are not technically viable then the rest of the alternatives are compared on an economic basis. The optimum solution will depend on

1. The type of problem
2. The number of end user being impacted, and
3. The possible solutions

Power Quality Evaluation Procedure



Basic steps involved in a power quality evaluation.

Power Quality Standards

- With the arrival of the computer age and the increasing trend towards miniaturization of electrical and electronic devices, power quality problems have taken on increasing concern.
- The designers of computers and microprocessor controllers are not welled in power quality issues.
- By the same time, power system designers and operators have limited knowledge of the operation of sensitive electronics. This environment has led to a need for power quality standards and guidelines.

Power Quality Standards

- IEEE: Institute of Electrical and Electronics Engineer
- IEC: International Electro technical Commission
- CENELEC: European Committee for Electro technical Standardization
- ANSI: American National Standards Institute
- NER: National Electricity Regulator
- SEMI: Semiconductor Equipment and Material International
- UIE: International Union for Electricity Applications.

International standards of power quality

- **IEEE Power Quality Standards**
- IEEE SCC-22: Power Quality Standards Coordinating Committee
- IEEE 1159: Monitoring Electric Power Quality
- IEEE P1564: Voltage Sag Indices
- IEEE 1346:Power System Compatibility with Process Equipment
- IEEE P1100: Power and Grounding Electronic Equipment (Emerald Book)
- IEEE 1433: Power Quality Definitions
- IEEE P1453: Voltage flicker
- IEEE 519: Harmonic Control in Electrical Power Systems

International standards of power quality

- **IEEE Power Quality Standards**
- IEEE Harmonics Working Group
- Single-phase Harmonics Task Force
- IEEE P519A Guide for Applying Harmonic Limits on Power Systems
- Interharmonics Task Force
- Harmonics Modeling and Simulation Task Force
- Probabilistic Aspects of Harmonics Task Force
- IEEE P446: Emergency and standby power
- IEEE P1409: Distribution Custom Power
- IEEE P1547: Distributed Resources and Electric Power Systems Interconnection

International standards of power quality

IEC Power Quality Standards:

- IEC61000 series, Electromagnetic Compatibility (EMC) defines for the following:

1. Part 1: definitions and methodology 61000-1-X: dealing with fundamental definitions, etc.
2. Part 2: environment 61000-2-X, deals with the characteristics of the environment where equipment will be supplied, and its compatibility levels.
3. Part 3: limits 61000-3-X, define the permissible emissions that can be generated by the equipment connected.
4. Part 4: tests and measurement 61000-4-X, testing and measurement technique provide detailed guidelines for measurement equipment.

International standards of power quality

5. Part 5: installation and mitigation 61000-5-X, provide guidelines for cabling of electrical and electronic systems, etc. They also describe protection concepts for civilians against the high-altitude electromagnetic pulse (HEMP) emissions from high-altitude nuclear explosions.
6. Part 6: Generic immunity and emissions 61000-6-X, defining immunity and emission levels required for equipment in general categories or for specific types of equipment.

International standards of power quality

- **SEMI Power Quality Standards:**

(Semiconductor Equipment and Material International)

1. SEMI F47-0200, specification for semiconductor processing equipment voltage sag immunity
2. SEMI F42-0600, test method for semiconductor processing equipment voltage sag immunity.

International standards of power quality

- **UIE Power Quality Standards:**

(The International Union for Electricity Applications)

- UIE-DWG, guide to quality of electrical supply for industrial installation,

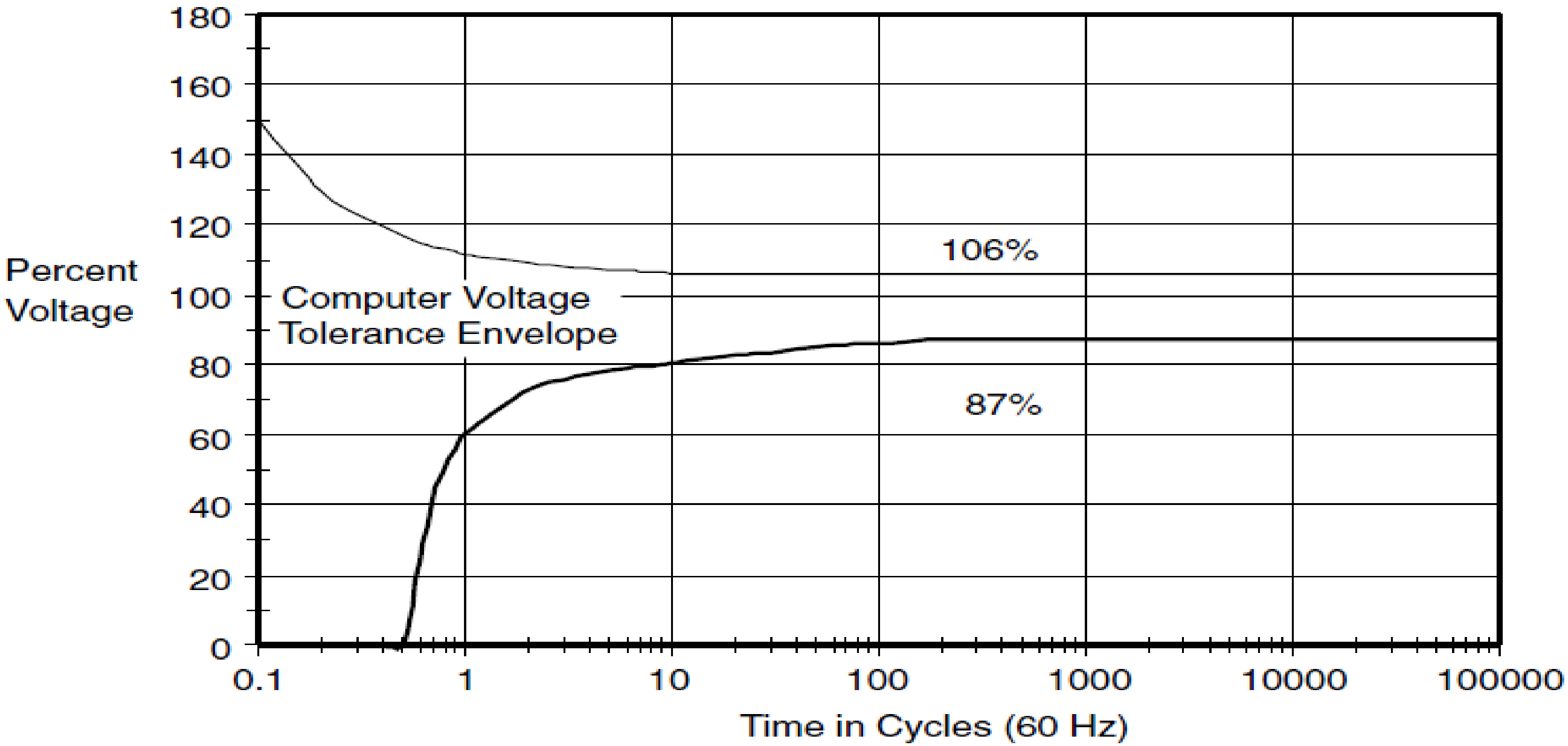
1. Part 1: general introduction to Electromagnetic Compatibility (EMC)
2. Part 2: voltage dips and short interruptions
3. Part 3: voltage distortion
4. Part 4: voltage unbalance
5. Part 5: flicker

CBEMA and ITI Curves

- *CBEMA - Computer Business Equipment Manufacturers Associations curve.*
- *ITI - Information Technology Industry Council curve.*

CBEMA Curve

- One of the most frequently employed displays of data to represent the power quality is the so-called CBEMA curve.
- A portion of the curve adapted from IEEE Standard 446 that we typically use in our analysis of power quality monitoring results is shown in Fig.



A portion of the CBEMA curve commonly used as a design target for equipment and a format for reporting power quality variation data.

CBEMA Curve

- This curve was originally developed by CBEMA to describe the tolerance of mainframe computer equipment to the magnitude and duration of voltage variations on the power system.
- While many modern computers have greater tolerance than this, the curve has become a standard design target for sensitive equipment to be applied on the power system and a common format for reporting power quality variation data.

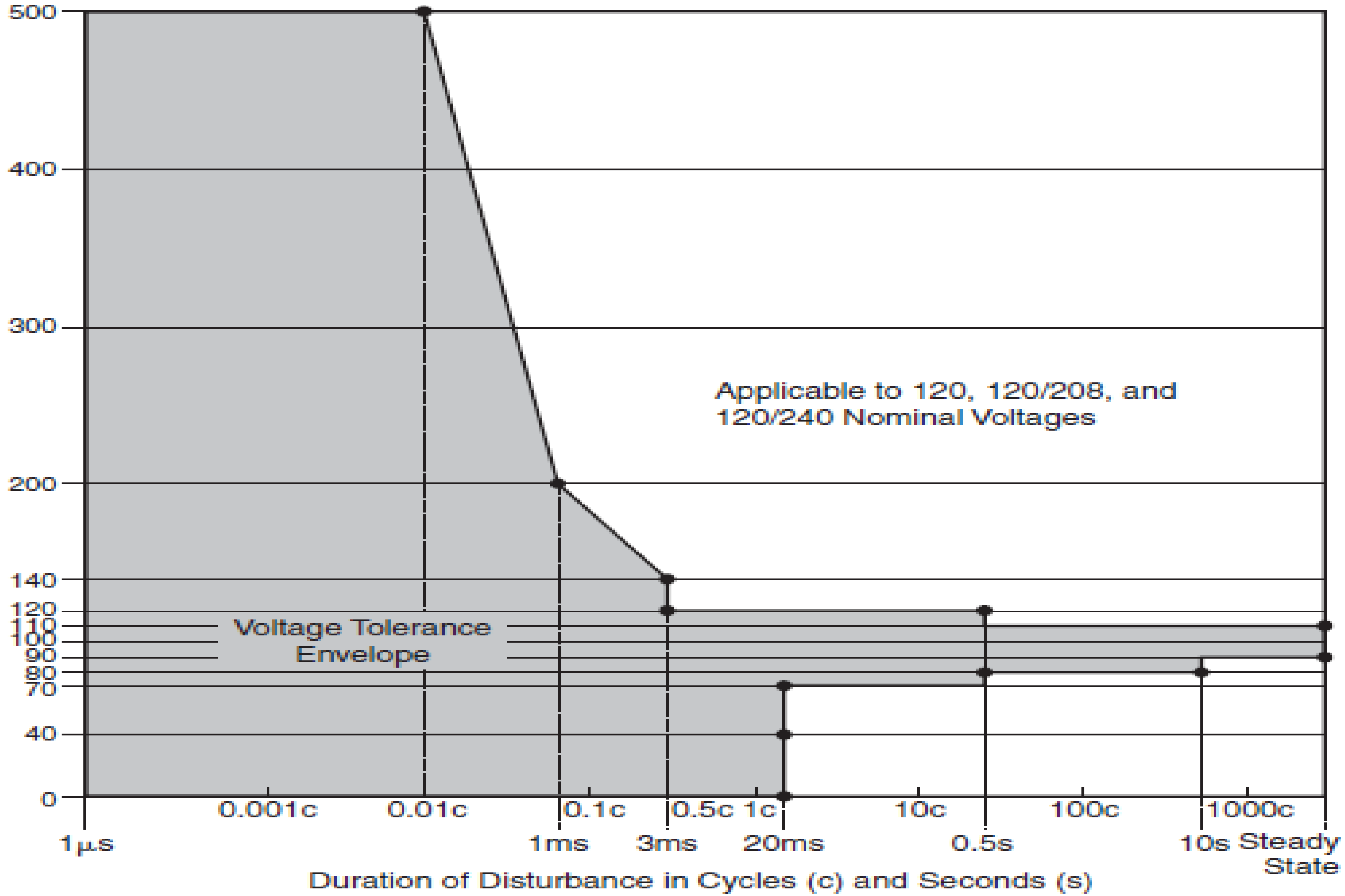
CBEMA Curve

- The axes represent magnitude and duration of the event.
- Points below the envelope are presumed to **cause the load to drop out due to lack of energy.**
- Points above the envelope are presumed to cause other malfunctions such as **insulation failure, overvoltage trip, and over excitation.**
- The upper curve is actually defined **down to 0.001 cycle** where it has a value of about **375 percent voltage.**
- We typically employ the curve only from **0.1 cycle** and higher due to limitations in power quality monitoring instruments and differences in opinion over defining the magnitude values in the sub cycle time frame.

ITI Curve

- The CBEMA organization has been **replaced by ITI** and a modified curve has been developed that specifically applies to common **120-V computer equipment**.
- The concept is similar to the CBEMA curve. Although developed for 120-V computer equipment, the curve has been applied to general power quality evaluation like its predecessor curve.

ITI Curve



ITI curve for susceptibility of 120-V computer equipment.

Information from the ITI curve

- *Steady-State Tolerances*
  - *+/- 10% from the nominal voltage*
  - *Normal loadings and losses in the distribution systems*
- *Line Voltage Swell*
  - *120% of the RMS nominal voltage, with a duration of up to 0.5 seconds.*
  - *Occur when large loads are removed from the system or when voltage is supplied from sources other than the electric utility.*
- *Low-Frequency Decaying Ring wave*
  - *a decaying ring wave transient which typically results from the connection of power factor-correction capacitors to an AC distribution system.*
  - *frequency of this transient may range from 200Hz to 5KHz, depending upon the resonant frequency of the AC distribution system.*
- *High-Frequency Impulse and Ring wave*
  - *the transients which typically occur as a result of lightning strikes*
  - *Wave shapes applicable to this transient and general test conditions are described in ANSI/IEEE C62.41-1991*

Information from the ITI curve

- *Voltage Sags*
  - *Sags to 80% of nominal (maximum deviation of 20%) are assumed to have a typical duration of up to 10 seconds, and sags to 70% of nominal (maximum deviation of 30%) are assumed to have a duration of up to 0.5 seconds.*
  - *heavy loads, as well as fault conditions in AC distribution systems*
- *Dropout*
  - *RMS voltage sags and complete interruptions of the applied voltage, followed by immediate re-application of the nominal voltage last up to 20 milliseconds.*
  - *occurrence and subsequent clearing of faults in the AC distribution system.*
- *No Damage Region*
  - *sags and dropouts which are more severe*
  - *continuously applied voltages which are less than the lower limit of the steady-state tolerance range*
- *Prohibited Region*
  - *any surge or swell which exceeds the upper limit of the envelope*